Floorplate Shapes and Office Layouts:
A Model of the Effect of Floorplate Shape on Circulation Integration

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Ermal Shpuza

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Floorplate Shapes and Office Layouts:
A Model of the Effect of Floorplate Shape on Circulation Integration

Approved by:

Dr. John Peponis, Advisor
College of Architecture
Georgia Institute of Technology

Dr. Sonit Bafna
College of Architecture
Georgia Institute of Technology

Dr. Ruth Conroy Dalton
The Bartlett, University College London
University of London

Dr. Philip Steadman
The Bartlett, University College London
University of London

Dr. Francis Duffy
DEGW

Date Approved: March 17, 2006

In memory of my mother, Shpresa Xhyheri Shpuza

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

cf	Convex Fragmentation
gd	Grid Distance
F	Actual floorplate
HF	Hypothetical fishbone layout
HG	Hypothetical grid layout
L	Actual layout
ocd	Overlapping Convex Depth
rgd	Relative Grid Distance

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Summary

This thesis proposes a model of understanding the constraining effect of floorplates on the integration of office layouts. The proposed model is based on the analysis of floorplates and layouts which is simultaneously configurational, global and robust. The study departs from two observations: first, there is a difference between the lifespan of shells and layouts; second, shells influence but do not determine the layouts than can be accommodated in them.

The thesis proposes two descriptions of shape which gauge their compactness and convex fragmentation based on configurational relations among modular units of shape. Shapes of actual floorplates are described according to the proposed measures leading to a typology of office buildings.

The space syntax research on workspaces has demonstrated that the integration of layout circulation affects the patterns of movement, encounter and interaction, which are linked to organizational performance. Actual layouts are described according to skewness and density of connectivity of linear maps leading to three alternative types of office layouts: sparse grids, dense grids and fishbones. Two ideal layouts of grids and fishbones, extracted from the typology, reflect opposing ways of increasing the layout integration and best represent open-plan layouts.

Experiments with hypothetical grids and fishbones generated systematically on theoretical shapes demonstrate strong but differing effects of shape on layout integration. These are subsequently confirmed by the analysis of hypothetical grids and fishbones generated into a large sample of actual office buildings in the US.

The relationship between floorplate shape and layout is mediated by the generative principle applied to the generation of layout. There exists an underlying congruence between a morphological typology of layouts (which distinguishes between fishbone and grid as alternative principles for increasing integration) and a morphological typology of shapes (which distinguishes between more compact and convexly unified shapes and shapes with wings). The findings highlight the distinction between constraint and determination. Floorplate shapes exercise underlying constraints upon the layout integration but they do not determine it.

The proposed model enhances the evaluation of existing building portfolios for their suitability for different types of office layouts and aids the design and planning of new work environments.

Chapter One

1.1 Introduction

This thesis addresses the question of how shapes of floorplates of office buildings affect the layouts accommodated in them. It constructs a model of investigation founded on the spatial analysis of shapes and layouts and proposes a theory of how the combination of design principles of layouts with characteristics of floorplate shape influences the spatial integration of office layouts.

The architectural research and professional practice on office environments has increasingly recognized the rift between rigid buildings shells and changing layouts, which mirror the ever-shifting and transient organizational requirements. The lessons learned from the inability of overly custom-designed shells to suit different clients, the prospects of organizational downsizing, exit strategies and subleasing are enhanced by an universal understanding among architects that office layouts are prone to continuous changes and modifications. The current awareness inside the architectural community about the sustainability of built environments in general and workplaces in particular gives the understanding of the relationship between floorplate shapes and layout configuration a particular importance. The issue of gauging the potential of floorplates for accommodating various types of office layouts is directly linked to the reuse, refitting, retrofitting and relocating organizations.

The shape of floorplate is a result of a multitude of factors and often of a process of reconciling many contradictions. Shells purposely built to accommodate office layouts are designed to meet the test of layout adaptability. Leaving aside the complex effect of other factors, the accommodation of various layouts per se generates enough intricacy for the floorplate design due to different occupancy of buildings and the ever-changing nature of management ideas. More than any other type, offices are the epitome of buildings whose shells should cope with a variety of layouts and changeability of requirements. Designed to fit all, or at least to fit many, office floorplates nevertheless exert constraints as well as offer potentials for various layout types that are accommodated in them. A model of understanding floorplate shapes will enable architects and clients to reach solutions that take full advantage of the potential of shells.

Architects act as advocates who reconcile between constraints and potentials of shells and programmatic requirements underlying layouts. The layout design has a twofold nature: understanding and translating organization requirements into the physical form of furniture arrangement; and second, recognizing the potential of shells for facilitating specific layout arrangements. Consequentially, there are cases where designers overpass constraints of shells and succeed in achieving good layout solutions, and contrary cases where layouts chosen by architects do not take advantage of characteristics of shells. The shape of floorplates, as a particular aspect of office shells, is one among the multitude of factors intervening in the design of an office layout. The thesis does not attempt by any means to offer normative guidelines about specific choices for office layouts resulting from characteristics of floorplates. In contrast, it aims at revealing the effects floorplate shapes exert on particular kinds of layouts. This knowledge will, at the least, aid recognizing the potential of floorplate shapes for allowing or constraining specific layout solutions, and at the most, will suggest design strategies as far as the configuration of the primary circulation is concerned.

The thesis addresses five issues which emerge from the different life span of shells and layouts as well as from the background of configurational studies which offer the thesis’s conceptual foundation.

The concern of relating layouts to the characteristics of shells is not new. Some studies have analyzed the effect of floorplate on particular aspects of layouts, for example the metric distance between workplaces as linked to organizational performance. At a more advanced level, research on office environments has focused on finding affinities between kinds of floorplates and types of office layout. The pioneering doctoral thesis of Duffy has proposed a theory of relating the sociological aspects of interaction and bureaucracy to the physical enclosure and subdivision of office layouts. The model is founded on the principal distinction between different longevities of shell, services, scenery and settings. The later ORBIT studies and Broadgate benchmarking have elaborated the typological analysis of floorplates in the light of best matches for office layouts. Other studies focusing on the relationship between physical aspects of layouts and aspects of organizational performance by BOSTI, ICFM and Steelcase share many methodological commonalities with the studies by Duffy and others at DEGW with regard to suggesting global correspondences between entire shells and entire organizations by aggregating local fits between parts of layouts pertaining to teams or individuals and regions of shells. Over and above the question of *whether* shells allow fitting specific layouts, this thesis inquires *how* the overall structure of layouts is affected by characteristics of shells. This is the *first* issue that this thesis confronts by emphasizing the importance of the relational correspondences among layout parts and the relational effect of floorplate regions. There is a paradigmatic association to studies in space syntax which propose configurational descriptions and analysis of space based on relations between elements considering all other elements in the system, by focusing primarily on the configurational analysis of the layout circulation.

As is often the case, due to the requirement of office buildings for accommodating most kinds of office layouts, shells in their unoccupied state consist of open spaces which are little differentiated, primarily due to the position of the core and the configuration of the building perimeter. Existing descriptions of floorplates have addressed local characteristics of sub-regions, especially the metric depth between core and perimeter, which have been related to kinds of layouts that can be best accommodated in them. The *second* issue addressed by this thesis is formulating descriptions of shape that recognize the continuous condition of spatial properties in floorplates by aggregating local conditions of infinitesimal units of floorplate shape in a configurational manner.

There are three main elements involved in this discussion: *shell*, (the *floorplate* being one aspect of it), *layout* and *organization*. Only the research of Duffy and others at DEGW has made an explicit distinction between the three and has constructed a model founded on the dual relationships between pairs of layout types, considered to represent specific organization models, and types of floorplate. Studies in space syntax have concerned the relationship between spatial features of office environments, for example circulation integration, and have demonstrated strong and significant correlations with levels of movement, interaction and awareness of people. The object of analysis of syntactic studies has constituted the *spatial system* confined by layout furniture, low walls and screens as well as elements of shell, including the building envelope, columns and core. There are no space syntax studies to date that have recognized two separate components of spatial systems in office environments, shells and layouts, let alone addressed the relationship between the two as a paramount issue in the design and planning of office environments. From the perspective of configurational studies, this constitutes the *third* issue of both methodological and principal nature tackled by this thesis.

As an architectural theory, space syntax suggests that built environments have a social dimension and that societies have a spatial logic. In 'Space is the Machine', Hillier has advocated that the *configurational* theory of space allows discovering the rules that underlie the generation of designs. It is argued that the architectural theory frees architects from the practice of generating knowledge based only on *precedent* cases. Studies by Duffy, Davis, Brill and Steel have in common the fact that generalizations about good matches between shells and layout types as well as between layouts and aspects of organizational performance are based on analyzing existing cases according to a precedent fashion. Similarly, space syntax studies on office environments have developed a knowledge base from the analysis of precedents demonstrating the existence of patterns of behavior related to characteristics of office environments. In contrast, Hillier's principles of linearity, contiguity, adjacency and extension have sought to discover the mathematical principles that order the construction of depth and integration, while Rashid's doctoral thesis (Rashid 1998) has suggested principles that underlie the effect of internal partitions on the experience of a moving observer. There are no studies that have aimed at discovering the theoretical principles guiding the constraining and generating effect of floorplate shapes on features of office layouts. The *fourth* issue raised by this thesis is the formulation of a theoretical model that allows understanding the mathematical possibility of the relationship between floorplate shapes and layouts.

In a generative level, the design of office layouts evolves around rules which are direct consequences of requirements posed by organizations. As far as we consider that floorplate shapes are important for generating or constraining office layouts, we are presented with the issues of negotiating between design principles of two different natures, of organizations and of shells, which do not necessarily match. The counter argument to this, will remind us that office floorplates *are* already designed to specifically accommodate office layouts satisfying current and future needs of organizations, hence no conflict is likely between rules generated from floorplates and those generated from client needs. However, a quick glance over the plethora of floorplate shapes and office layouts and the consideration about changes as well as exchanges between shells and layouts suffices to make this subject worth considering. The *fifth* issue addressed by this thesis comes about as a philosophical ramification of dealing with rules and constraints originating from two different sources and the prospect of understanding their mutual effect.

1.2 Inquiry and Methodology

Office layouts are on the one hand spatial materializations of the organizational criteria and on the other are inseparable from their container shells. The analysis of office layouts in their actual state as contained inside shells is marred by the issue of understanding the degree to which these layouts reflect design principles which respond to organizational requirements, and the degree to which they reflect the characteristics of shells. The understanding of these two separate effects in their own right is not possible by analyzing real conditions of layouts contained in their container shells. Regardless of the number of cases that may be observed and the size of the sample that may be formed, no meaningful generalization can be drawn by aggregating conditions of pairs of shells and layouts, since each pair is affected by particular requirements as well as individual design approaches.

The description and analysis of shells, and floorplate shapes in particular, can proceed on its own right without regard to the present or potential layouts to be accommodated in them. This is in contrast to the fluid and ever-changing layouts which cannot be considered outside their containers. I propose to address the issue of dealing with the two interdependent factors of pairs of floorplates and layouts by keeping one side constant. Accordingly, it is possible to understand the effect of various floorplates on a specific hypothetical layout by analyzing the conditions of this layout after it has been accommodated in these floorplates. This requires the conception of a generic layout in an idealized form as a design realization of clear composition principles. Each realization of this hypothetical layout into a specific form (after being introduced into floorplates) would allow gauging the effect of floorplate shape by means of comparative experiments with one or few layouts introduced on a large sample of floorplates.

Despite pertaining to a similar logical abstraction as the above, the opposite of this, i.e. the analysis of various layouts applied into a single floorplate, for example analyzing various floors of a high-rise building occupied by different tenants, does not promise the same potential because there is no good way to distinguish those differences between interior layouts which arise due to different design programs and approaches from the differences that arise from the effect of floorplate shapes.

The difference between rigid shells and fluid layouts, which was emphasized above, not only represents the source of the theme of this thesis, it also suggests the foundation for constructing its methodological apparatus which consists of two main pillars: First, few ideal layouts will be formulated based on key composition principles encountered in actual office layouts. For this, a large sample of office layouts will be analyzed with the assumption that the effect of container shells on them is evened out due to the size of sample in consideration. Second, the proposed hypothetical layouts will be introduced into the floorplates of the same sample and will be analyzed in order to investigate the effect of floorplates on them. Differences found among layouts after they are inserted into floorplates will be attributed to characteristics of floorplates and this will constitute the basis for formulating a theory of how floorplate shapes affect layouts.

There are three additional intermediate steps necessary for this model: First, searching for or proposing descriptions of shape which take into account spatial characteristics of continuous environments of office shells and which anticipate spatial features of future layouts. Second, justifying the choice for spatial descriptions of office layouts which are related to important behavioral aspects in offices linked to organizational productivity. Third, understanding the mathematical possibility and scope of the effect of shapes on layouts by means of experimenting with hypothetical layouts introduced into theoretical shapes. The following section gives a general overview of the thesis.

1.3 Overview

Chapter Two reviews the research which has addressed the relationship between spatial characteristics of building plans and aspects of layouts. The review includes studies with a particular focus on office environments and organizations as well as studies which have a more general scope and share their methodological approach with the thesis. The review identifies the lack of depicting important aspects of the global spatial structure of layouts as the basis for understanding how building plans in general and floorplate shapes in particular influence layouts. The chapter reveals the need for constructing a robust and global model of the relationship between floorplate shape and layout based on the same domain of configurational analysis for floorplate shapes and layouts (**figure 1.1**).

Chapter Three reviews the main theorems, definitions and analytical methods of space syntax, focusing on the research on office environments. The need for configurational descriptions, which make it possible to evaluate global spatial properties based on relative conditions of local components, suggests the necessary association of the thesis with space syntax theory and analytical techniques. The review identifies the Integration[1] of layout circulation as the most important spatial index which is demonstrated to influence the potential for movement, encounter and co-presence at the scale of the organization as a whole, hence organizational productivity (**figure 1.1**).

Chapter Four reviews studies on the description of shape. It is argued that descriptions with discrete elements used by geographers and geometers either lack the ability to cope with complex shapes with holes, as is the case of the usable area of floorplate shapes, or are based on abstract geometric elements that have no association with the human perception of space.

[1] Capitalized words are used for variables. Lower case words refer to the common concept.

Descriptions based on modular and infinitesimal representations of shape, proposed by the research in architecture, architectural morphology and space syntax in particular, are not sensitive to metric dimensions and affinity transformations of shape, and fail to gauge the overall characteristics of shape over and above addressing differences between regions of shape. The review identifies the need for new robust and global descriptions of shape. It jumpstarts an inquiry of properties of shape founded on spatial perception according to a configurational analysis of modular representations, hence providing the premise for making these descriptions compatible with configurational descriptions of layouts (**figure 1.1**).

Chapter Five proposes two new descriptions of shape, Relative Grid Distance and Convex Fragmentation designed to address two basic human perceptions of covering a metric distance and changing the direction of travel. The Relative Grid Distance expresses the compactness of the shape as a degree to which it differs from the square. The Convex Fragmentation expresses the convexity of the shape as the number of turns needed to connect its regions. The two shape indices are calculated for a sample of fifty floorplate shapes of office buildings using a computer application designed as part of this research. This analysis concludes with a new typology of office floorplates which is based on combined values of Relative Grid Distance and Convex Fragmentation. It includes floorplate types of: blocks, bars, small and few internal cores, many and large internal cores, pavilions and wings (**figure 1.1**).

Chapter Six is aimed at formulating ideal layouts based on principles which are distilled from the analysis of actual office layouts. The analysis uses the same fifty examples as for the analysis of floorplate shapes including cases representative of the best practice in architecture as well as different layout types recognized by architectural research and practice. The analysis utilizes the conventional representation of space syntax with linear representation of the layout circulation. In addition to existing measures used generally by space syntax, the thesis proposes new descriptions of layouts based on the statistical distribution of these conventional measures..

Based on combined degrees of density, which is measured by Connectivity, and differentiation, which is measured by Connectivity Skewness, the thesis proposes a new typology of office layouts composed of three types of layouts: biased, unbiased sparse, and unbiased dense. Comparisons are made between layout characteristics and shape indices of their containing floorplates according to three split sub-samples in order to sketch early hypothetical ideas rather than prove the existence of objective links between layouts and floorplates. Two ideal layouts are proposed. Grid layouts are ideal abstractions of unbiased and dense actual layouts, and fishbone layouts are ideal representations of biased actual layouts (**figure 1.1**).

Chapter Seven is aimed at discovering the mathematical principles underlying the effect of floorplate shapes on the Integration of layout circulation. The two proposed ideal layouts of grids and fishbones are introduced into theoretical shapes derived by controlled deformations of three basic shapes by removing one or two shape units. The analysis has revealed the existence of shape regions where the removal of shape units does not affect the Mean Depth of layouts. Strong and significant correlations between layout Integration and shape Relative Grid Distance and Convex Fragmentation for the two ideal layouts and the distinctly contrasting dependencies between them have formed the basis for formulating two hypotheses on the effect of floorplate shapes on layout Integration according to different generating principles of layouts (**figure 1.1**).

Chapter Eight seeks to test the hypotheses by analyzing the ideal layouts of grids and fishbones introduced on the twenty five floorplates from the original sample. Strong and significant correlations are found between layout Integration and Relative Grid Distance and Convex Fragmentation of floorplate shape. The chapter includes the conclusions for the thesis, implications for architectural research and practice and suggests directions for further research.

The next chapter will proceed with reviewing the research on the relationship between aspects of shells and building plans and characteristics of layouts contained in them.

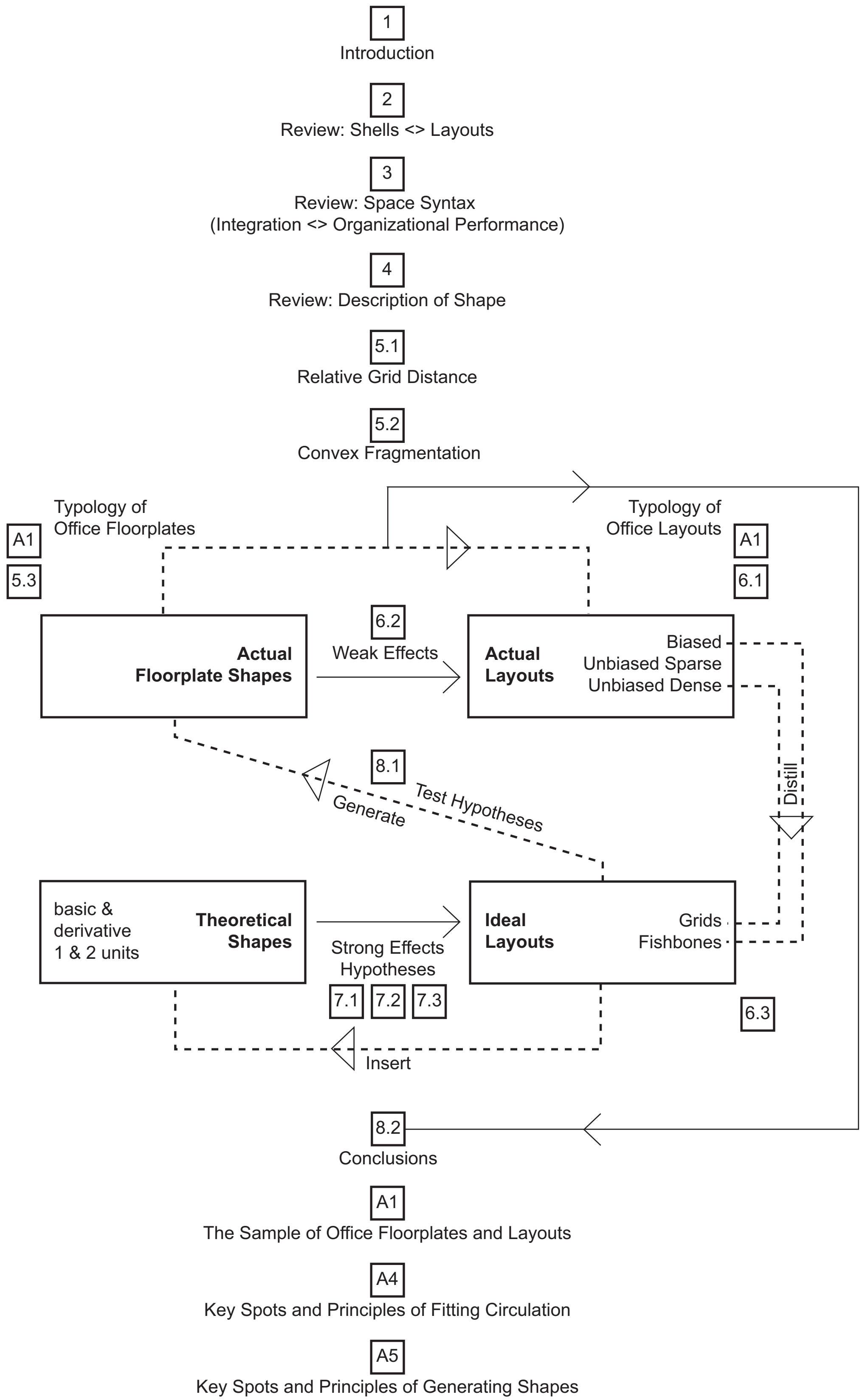


Figure 1.1: The structure of the thesis.

Chapter Two

Review of Studies on the Relationship between Building Form Metrics and Aspects of Layouts

Outline

This chapter reviews studies which address the relationship between formal aspects of office shells and characteristics of office layouts, and studies which, from a more general viewpoint, address the effect of built form on internal metric distances and the nature of fitted adjacency graphs. Studies by Duffy and other at DEGW recognize the principal distinction between rigid shells and dynamic layouts and propose fits between types of layouts and types of shells. This chapter focuses particularly on two problems of these studies: first, the issue of drawing conclusions of a global nature regarding the fit of organizations into shells by means of aggregating local matches between sub-regions of shells and parts of layouts without considering their global structure of shells and layouts; second, the issue of using different domains of analysis, where shells are quantitatively described based on metric features while layouts are described qualitatively according to degrees of subdivision and differentiation. Studies which propose significant links between characteristics of building form and travel distances are discussed due to implying useful methodological directions for the thesis, despite originating from different research agendas.

2.1 Office Floorplates

The thesis recognizes the floorplate of office buildings as one of the most important aspects of building shell and focuses on the description of its shape. The shape of an office floorplate is defined as the area of the usable space bound by the building perimeter, where atria and cores have been removed.

Pile (1976) describes the space within office buildings as uniform and characterless and argues that its origins are to be found on the economics dictating the need for fulfilling requirements of the largest possible number of unknown tenants, as far as speculative building is concerned.

> “It might seem to be a basic reality that the architecture of office buildings would be a controlling factor in the nature of the office inside. Actually, to a degree quite disturbing to architectural critics and theorists, offices are surprisingly independent of the buildings that house them. We find excellent offices inside bad buildings and poorly designed offices inside good buildings; we find old-fashioned offices in modern buildings and modern offices inside old buildings. This is a situation that … raises some disturbing questions about office building architecture.” (Pile, 1976: 21)

Especially in the case of offices built in urban locations, site constraints, building regulations, code requirements, and zoning laws combined with the drive for maximum profitability have generated a maximum of volumetric mass stretching all the way to the permissible limits. The powerful effect of zoning laws and codes can be best grasped when deep plan American offices are compared to narrow floor plans of European offices resulting from strict regulations on natural light and outside views in workplaces. In addition, the European national context in the UK, Germany, Sweden, Italy and The Netherlands has affected varieties in office design through differences in ownership structure, historical character and preservation, democratic nature of planning processes, multi-leveled bureaucratic phases of building permission as well as cultural aspects (van Meel 2000).

The design of office buildings, according to Pile, follows two main patterns: The first is an outside-to-inside approach whereby an ideal basic plan in terms of floorplate configuration and core location is established. This category includes cases which volumetric compositions breaks away from the permissible mass allowed by zoning and cases founded on revolutionary engineering and environmental systems, SOM’s 33 West Monroe, Foster’s Commerzbank and Swiss Re, and DEGW’s Apicorp. The second is an inside-to-outside approach where a pre-established workstation module or layout influences the configuration of perimeter, the depth between core to perimeter, the proportion of bays, the structural grid and window mullions. This approach is reminiscent of office floorplates in the US before the recession of the late eighties whose main characteristic is the jagged perimeter providing a large number of corner spaces to accommodate numerous middle-management offices. These building plans ceased to be built soon after the flattening of management schemes following the recession giving way to buildings with more compact floorplates.

Often, the two design approaches precipitate into solutions which gain the status of best meeting the market requirements in a given time. For example, all speculative offices designed by the Atlanta-based firm Cooper Carry Architects during the period 1999-2001 conform to a basic type of a rectangular 245x115 ft plan, a 100x20 ft central core, and a 40 ft deep tenant space (**figure 2.1**). This type is widely spread particularly in American suburban office parks where site constraints are non-existent.

Offices of corporate headquarters and those built in prestigious urban locations are in stark contrast to the speculative ones. A glance over 60 plans of offices designed by Skidmore Owings and Merrill during the period between 1957 and 2004 demonstrates an exciting variety of different configurations despite the fact that many cases conform to solutions with central core (**figure 2.2.1 - 2.2.3**). The range of office plans widens considerably when European offices and offices in converted buildings are taken into account (Steadman 1994).

Office buildings, despite being influenced by market conditions like no other building type, demonstrate nevertheless a wide diapason of floorplate shapes which arguably exert equally varied impacts on office layouts they accommodate. As emphasized by Duffy (1976) office buildings affect layouts via several aspects including the metric depth between core and perimeter, the size and proportion of bays, services and the structural and mullion grids. The thesis considers the shape of floorplate as a paramount characteristic of plans to affect layouts. It focuses particularly on the study of floorplate shapes as the key aspect of office buildings to affect internal office layouts. The object of study is crystallized towards the description and classification of floorplate shapes of the existing stock of office buildings without inquiring further into the origins and factors that have influenced floorplate types, including differences between low-rise and high-rise buildings.

2.2 Office Layouts

Office layouts have evolved in tight conjunction with the development of managerial models and changes in the nature of organizations. The spatial composition of layouts directly reflects programmatic requirements for adjacency, clustering, isolation, control, supervision, hierarchical stratification and functional processes. The evolution of offices from the elemental solitary dens of medieval palaces (Pevsner 1979) has produced a range of types including cellular offices, regimented bull pens, bürolandschaft, combi-offices and the more recent office clubs, to mention a few (Duffy & Powell 1997).

A quick glance over a sample of fifty layouts from the last five decades (refer to Appendix 1), shows consistent degrees of repetition and modularity in the arrangement of workstations and cellular offices. Despite the wide variations between office layout types, the modularity of spatial conditions between layout elements and furniture components is one characteristic that pertains to almost all kinds of office layouts, especially when large and medium size offices are concerned. Primarily, this is due to the nature of office organizations where the majority of work processes and specializations belong to the large heavy base of managerial pyramids and to the fact that similar work processes are accommodated well in almost identical spatial arrangements and furniture.

The modularity of office layout is a principal characteristic which suggests and justifies a methodological model based on the comparative analysis of few layouts applied on a large sample of office floorplates. Hence, modularity is considered a key spatial principle for composing future ideal layouts based on abstracted spatial conditions distilled from actual layouts.

2.3 Duffy's Model: Affinities between Shell Types and Office Layout Types

The issue of describing floorplates from the viewpoint of the performance of fitted layouts brings the thesis at the same starting line with the research of Francis Duffy and others at DEGW. Duffy developed his seminal doctoral research (Duffy, 1974) into a model of finding affinities between features of office shells and different organizations (Duffy, Cave & Worthington, 1976) that addresses for the first time the complex link between the static *container* shell and the dynamic *contained* layout, which expresses different organizational ideas. Duffy makes the distinction between the *static* shell of office building that is designed to withstand changing requirements of organizations during the entire lifetime of the building, and the *flexible* scenery and sets that vary periodically according to requirements of organizations.

The model relates the sociological dimensions of organizations to physical properties of office layouts through a bimodal and typological approach where both physical and sociological aspects are described separately and their relationship to one another is measured in a quantitative way. The study suggests, in one hand, a descriptive and analytical model for office shells, and in the other hand, normative guidelines for understanding what kinds of layouts, consequentially office organizations, are suitable to occupy certain shells or parts of them. The model contributes concepts, representations and measures for both sides of the equation: the description of shells and the categorization of layouts. The testing of the two poles of the model against each other is founded on the concepts of *fitting* and *affinities* between layouts and shells. The study is critical to theories that consider behavior as cause of the environmental effects of layouts and buildings – the variables and levels of criticality, according to Duffy, are far too many to allow a clear understanding of such connection. Instead, differences between kinds of office work and management styles are recognized to be crucial for choosing a particular layout, while relaxing other features that add complexity to the relation. The reality of design incorporates ideas and constraints of the geometrical nature related to buildings.

The model, later enhanced with new concepts on office organizations (Duffy and Powell 1997), constitutes four main parts: first, the division of office environments into three components of *shell*, *scenery* and *sets* according to their lifetime and flexibility of adjusting to changing needs of clients; second, the description and classification of shells according to the kind of spaces into which they can be divided and ways they can be merged; third, the description of profiles of organizations and resulting sceneries; four, the fitting and accommodation of sceneries into shells, as well as affinities between various kinds of shells and sceneries.

The appraisals and descriptions of shells, layouts and organizations and their mutual relationships are interdependent and are often studied in conjunction with each other. For the purpose of this thesis, the review will focus mainly on the first pair comprising shells and layouts, without reviewing in depth the second pair comprising layouts and organizations. Therefore, this section will discuss primarily the first half of Duffy's model including the main definitions and descriptions of shells and the fitting between shells and layouts. A detailed review of the section of Duffy's model that addresses the description and classification of layouts and organizational variables is given in the Appendix 2.

2.3.1 Definitions of shell, scenery and sets

The physical aspects of office environments are categorized into three components of *shell*, *scenery* and *sets* according to their longevity and likelihood of change (**figure 2.3**). Duffy states that:

> Office design is like the design for the stage. The shell of an office building is equivalent to the bare stage which is built for as long as the theatre will last. The scenery is the assembly of props required for a production i.e. a tenancy. The sets are the various dispositions of scenery needed for the different scenes of the play. (Duffy, 1974: 4)

> Shell is defined as all that is provided throughout the lifetime of the building: the structure, the envelope and the basic services. (ibid.: 8)

> Scenery has a much shorter life than the shell. Its role is to take up the tolerance between the precise needs of the tenants and the loose fit of the building shell. (ibid.: 10)

> Users' adjustments of 'scenery' create the 'sets' for the office scene. (ibid.: 5)

The term *floorplate* used in this thesis, represents the two-dimensional projection of the *shell*, while the term *layout* relates to the term *sets* used by Duffy. Almost all aspects of analysis of shells address their 2D projections, hence floorplates. For the purpose of reviewing Duffy's work, the original terms of *shell* and *sets* will be used by making the necessary links to aspects of shells that concern the floorplate shape.

2.3.2 Description and classification of shells

The model of Duffy uses several methods for measuring and evaluating the office space contained in shells: *gross floor area, net floor area, service area, rentable area, ratio of gross to net area* that are similar to the BOMA[1] standards used in the USA. For the open office planning, the study proposes two methods for evaluating shells: first, the *size and proportion of the shell*, which describes globally the geometry of shells; second, the *size and proportion of each structural bay,* which are local geometrical descriptions of regions of shells (**figure 2.4**). The two descriptors are suggested as normative values for suitable design through charts that relate the proportion of shape with the net area. Several factors are suggested to affect the shape of the shell and its relation to the core: density of development, light and overshadowing of the site, the means of escape and the maximum travel distance.

[1] BOMA – Building Owners and Managers Association (http://www.boma.org)

The grammar of description of office shells is based on three elements: the location of the core in relation to the shell; the position of major circulation routes; and the depth of office space. Different locations of the core in relation to the shell, *internal, semi-internal,* and *external* result in spaces with different depths from core to perimeter. Thus, shells are characterized by the depths of the spaces they provide: *very deep, deep, medium* and *shallow* (**figure 2.5**). Very deep space is described as being over 20m deep, deep space as being 11 – 19m deep, medium as 6 – 10m, and shallow space as being 4 – 5m deep. For example, a long and narrow building can only be subdivided into shallow spaces, while a rectangular building with a central core can provide both shallow and medium depth spaces. The position of cores also determines the starting point of major circulation systems. Corridors are classified: first, according to whether they serve spaces *in one or both sides*; and second, according to their configuration: *linear* connecting two separate cores, *O-shape* or *Z-shape* surrounding central cores. For very deep spaces, circulation systems are free from constraints of core or shell, thus allowing several configurations.

One requirement of organizations is to relate workgroups to spaces according to the needed area in square feet. With this regard, shells are classified into categories based on the types of spaces they can provide: *small, medium, large*. According to this description, the shell is dissected in several ways often with superimposing geometries to measure the *flexibility* and allowance of shells for accommodating departments and workgroups of an organization or different tenants in a floor (**figure 2.6**). Shells that can be subdivided into a variety of ways allowing for *shallow*, *medium* and *deep* spaces (when depth is concerned), as well as *small*, *medium* and *large* spaces (when area is concerned) are described as being more flexible than shells which provide less subdivision options. Shells are also analyzed and evaluated with respect to reconciling four kinds of grids: *structural, constructional, servicing* and *planning*. In planning layouts of cellular offices, constructional grids and window mullions grid, gain primary importance, whereas in planning open-plan offices, structural grids mostly influence the layout arrangement. Different choices of combining the four types of grids have been suggested to affect the choices for interior layouts.

Similar to Duffy's index of size and bay proportion, BOSTI utilizes three categories of spaces for planning groups of workspace in large areas: *loft*, which had as much depth as frontage; *band*, which was a longer and narrower space with frontage on the core of the building and a shallow depth to the perimeter; and *giant floor*, as the wide and deep sections of floorplate encountered in suburban office developments (Brill, Margulis & BOSTI, 1985).

2.3.3 The fit between shells and layouts

In 'Planning Office Space' (Duffy, Cave & Worthington, 1976), shells have been analyzed and evaluated from the viewpoint of enabling the efficient accommodation of organization. Four types of shells have been used for gauging their effect on office layouts: *speculative*, *narrow central*, *large old house*, and *open plan*. After fulfilling the requirement of the size of area, shells have been tested against the *space stock capacity* and *clustering capacity,* (**figure 2.7**). The first is related to the earlier discussion on the flexibility of a shell to contain spaces with different sizes, and the second to the capacity of shells to bring these spaces together, for instance the open plan has a high capacity with this regard. Layouts or sets are categorized in four types of cellular rooms for one to five persons, group space rooms for five to twenty people, traditional open plan, and burölandschaft layouts. Duffy argues that shells exercised constraints on the types of layouts they could accommodate depending on characteristics of *depth* and *area size* of spaces as well as on space stock and clustering capacities. For example, shallow spaces could easily be subdivided into cellular rooms; medium depth spaces are problematic for single person rooms but could accommodate easily partitioned group spaces; deep spaces are suitable for burölandschaft layouts but not suitable for cellular accommodations.

DEGW's Building Appraisal techniques have played an important role in the benchmarking studies for the Broadgate and Stockley Park projects (Duffy et al. 1998). Robust classification of shells and the formulation of shell typologies (**figure 2.8**) are based on the descriptions of shells and servicing systems from the viewpoint of accommodating different generic types of office as well as accommodating change (**figure 2.9**).

The methodology of studies by Duffy and others at DEGW is based on three main pillars: first, definitions and descriptions of shells and the typology of shells; second, descriptions of layouts and the resulting typology of layouts; third, discovering the fittings and affinities between shell types and layout types.

2.4 The Need for Global Descriptions of Layouts and Floorplates

The relevance of Duffy's research for the thesis is multiple. It divides the elements of shells according to the lifecycle; it sets up an analytical model based on two components: the physical long-term shell and the short-term organization requirements as translated into layout solutions. Duffy's model for describing shells from the viewpoint of office layouts is powerful and robust. It proposes new measures and evaluating criteria for aspects of both shells and layouts and bridges between the two by offering normative guidelines and examples that signify good matching. The study suggests ways of understanding constraints and possibilities of shell for allowing certain organizations to function normally.

Despite the fact that the model is robust and produces a solution that is global, i.e. it accommodates the entire organization inside a shell, the *fitting* between shell and organization is based on the aggregation of local correspondences. The benchmark for testing whether a shell is suitable for an organization is the allowance of shell for subdivision into regions with certain areas or depths that suit the organization teams. The translation between organization requirements and shell features is supported by the pairs 'area of space – team', or 'depth of space – team'. Local allowances combined with each other are then combined into global findings. For instance, the space stock capacity characterizes the shell in its entirety by checking whether the shell can be subdivided into a given list of sub-regions required by the organization. Global features such as proportion of floorplate dimensions, the capacity for space stock and clustering, the depth of a space, the configuration of the circulation system and the matching of different grids when discussed in the light of what they allow, take into account what smaller or local set of spaces shells contain. The model can thus be expressed into three simplified components:

1) (list of organizational requirements) (translate into) (space size, space depth);

2) (space size, space depth) (check whether) (floorplate contains, can be divided into);

3) (merging, adjacency between space units) (check whether) (floorplate permits).

Of particular interest to this discussion is the configuration of circulation systems allowed by combinations of shell and core geometry. The significance of circulation is reduced into the kinds of local spaces circulation creates as remainders. While often corridor systems divide different tenants rather than teams of the same organization, Duffy's study stops short of recognizing the potential of the circulation system to guide the overall logic of the layout, over and above checking for merging and clustering capacity of the remainder spaces. As shown by space syntax studies, which will be discussed in Chapter Three, the circulation system directly affects degrees of movement, co-awareness and co-presence among staff. The circulation system due to having the potential for affecting interfaces between individuals and teams serves as the paramount element for translating organization requirements into layout arrangements.

The other issue of a both technical and conceptual nature arises from the fact that the depth between core and perimeter considers perimeters parallel to the skin and does not work well with changing depths and curvilinear perimeters, and, most importantly, it is based on the analysis of the area projected from the core to perimeter leaving thus uncovered areas on the corners of the shell (**figure 2.10**).

The bridging between the two components of the model is also problematic due to the highly *quantitative* nature of descriptors of shell that is matched against the *qualitative* characterization of layouts. While shell descriptors are about size, proportion and metric distance, layout types take into account considerations of connectivity between departments or between workspaces. Any matching between shells and layouts is thus supported by comparisons to precedent cases with similar characteristics, without being supported with quantitative data. Due to the countless variations of layouts, any qualitative description that relies on comparison to precedents is approximate by nature. This thesis suggests that it is necessary to use methods that assess the performance of layouts quantitatively rather than qualitatively. Thus, the fit and the proposed affinities need to be based on components that have been analyzed equally in a quantitative manner.

In Duffy's work, office sets are shown by diagrams with graphs of relations between parts and teams that recognize different levels of autonomy and interaction. While depicting well key characteristics of office layouts, this representation does not surpass the organization realm to describe floorplates on one hand, or the fit between floorplates and layouts on the other. What Duffy's model takes into account is the space needed for accommodating various teams of an organization and how a shell allows it by the virtue of the *space stock capacity*. The *clustering capacity* is the only measure that comes close to gauging what floorplate can offer to enable structures of relations among teams and groups as shown by graphs, without, however, showing exactly how the correspondences between characteristics of floorplates and those of layouts are matched.

The thesis argues that a model that is to find connections between the geometry of floorplates and structure of layouts should incorporate measures of the same realm.

2.5 Floorplate Shapes and Travel Distances

The minimization of travel distances between locations in a building and the optimization of office layouts for proximity between related departments has occupied an important place in the office planning theory and research in the past. This section reviews the studies that have addressed the relationship between travel distances and the configuration of floorplates due to the fact that, by pinpointing direct links between travel distances and floorplate shapes, these studies suggest the possibility of relationships between other aspects of layout and characteristics of floorplate shapes.

As early as 1928, Krasil'nikov (Cooke, 1975) proposed a mathematical model that reveals the relation between the geometry of floorplate and the travel time needed to distribute people in their workspaces from a single building entrance. His functionalist approach considers the form of the architectural object as result of many laws and conditions that can be revealed by using mathematics. The study assumes constant volumes of a small sample of theoretical buildings, and shows how the evacuation time, i.e. travel distance given controlled travel speeds, changes due to the shape of floorplate. Although the simplified model does not represent the actual travel that occurs in an organization, it reveals interesting differences that are attributed only to the geometry of floorplate, (**figure 2.11**).

Merkel and Merten (Boje, 1971) searched for the optimum number of floors of a building that would minimize travel distances from any point to all other points in a building with circular floorplate. Similar to Krasil'nikov, the optimum solution starts with the premises of a constant building area and two known speeds of walking and operation of lifts. The study proposes that a building with 34 floors and an area equal to 1176 m2 provides the best solution for minimizing travel distances (**figure 2.12**).

Tabor (1976) considered the minimization of travel distances between related teams or departments as an important aspect of the performance that directly enhances work efficiency. The study reveals the direct dependence of distances between locations in the floor from the configuration of the floorplate, specifically, by showing how the Average Distances between destinations are affected by the geometric form of floorplates in three theoretical examples of *slab*, *cross*, and *court* (**figure 2.13**). The average distance is subject to whether travels are occurring between locations that are nearby or distant. Tabor uses the index of the Propensity of the user of the building to make shorter trips, which expresses the effectiveness of a layout to place related activities in a proximity to each other. The value of Propensity is 0 for random destinations and increases for shorter trips. As the propensity to make shorter trips increases, the average trip decreases. Average Distances for high values of Propensity do not vary much from shape to shape, but it is for lower values, i.e. for long trips in badly planned layouts or unknown organizations, that the effect of floorplate shape becomes evident: the cross works considerably better for minimizing travels distances than slab or court. A similar account is given for the comparison between average values of *rectangular* and *straight-line* distances in five theoretical floorplates (**figure 2.14**). Based on this study, Steadman (2003) demonstrates how plan configuration affects the travel distances between day-lit strips in buildings.

Willoughby (1975) regarded the minimization of distances in buildings as a measure of efficiency and expanded on Tabor's work by searching what circulation scheme, in one floor or combined in a multi-level building, matches organizations with a given number of departments. The experiment considers floorplates occupied by many tenants or organizations with many departments. Mean Lengths of trips internal to each department are compared across a sample of five basic plan shapes of *slab, court, cross, fishbone* and *open-plan* populated with 1 to 12 departments of equal size (**figure 2.15**). The open-plan gives the shortest travel distances for all cases, whereas other floorplates give various results depending on how departments are spread out. The study rates the open plan and fishbone floorplates the best for allowing the highest flexibility and demonstrates that tight fits between circulation patterns and floorplate shapes lead to difficult balances, which can be easily destroyed due to alterations of the circulation pattern.

Experiments of Tabor and Willoughby reveal how the configuration of the circulation scheme affects the travel distances in large buildings and how building forms affect the choice for internal circulation patterns. The models consider equal size rooms arranged along corridor systems in a diagrammatic way; hence, the analysis of the circulation systems schemes is easily interchangeable with the analysis of floorplate shape. There is an obvious contribution to be drawn from these studies. The methodology of the research has utilized theoretical forms of circulation and a distribution of departments acquired through a simple mathematical model. Similarly, layouts generated through simple configurational concepts can be applied over a sample of floorplates with the purpose of evaluating their performance and the effect of floorplate characteristics. Tabor's and Willoughby's research, however, stops short of aiding both the evaluation of floorplate and the assessment of layout performance. No characteristics of the theoretical floorplates have been measured; hence the model cannot be applied on floorplates that do not distinctly fall in one of the theoretical types.

The minimization of travel distances is one aspect of layout performance, which benefit is disputable having in mind the research of Allen (1977) and Granovetter (1983) that advocate the generation of knowledge and increased performance when contacts among members of different departments are stimulated. Nevertheless, the significance of the research of Krasil'nikov, Merken and Merten, Tabor and Willoughby consist on the fact that they pioneer the investigation of shapes of floorplates to discover effects on the contained organization and provide sound evidence for the existence of direct effects of shape on aspects of layout performance, in this case the metric distance of travel between departments. The accomplishment of the research cited in this section is due mostly to the mathematical models that provide proof for the variance of internal distances from the configuration of the built form.

2.6 Models of Compatible Representations between Floor Plans and Organizations

Matela and O'Hare (1976) propose an analytical model based on equal domains for assessing the fitting between contained organizations and the container complex of spaces, where spatial layouts as well as organizational networks have been represented with graphs. The loose fit between buildings and potential organizations is expressed by enumerating subgraphs (organizational networks) contained by original graphs (spatial layouts). The enumeration of how many different sub-graphs may fit in the graphs representing architectural plans gauges the degree of *adaptability* of forms, while the enumeration of how many different ways sub-graphs may be arranged within the form gauges the degree of *flexibility* of forms. Matela and O'Hare remark the potential of *polyominoes*[2] (Golomb, 1996) with cyclic graphs, i.e. rings, for accommodating various graphs (**figure 2.16**). Due to the modular size of cells, such polyominoes are associated with fat and compact shapes that have consequently higher potential for adaptability and flexibility.

Using identical representations for both sides of the relationship, Steadman (1983) bridges between the morphology of form and the structure of organizations by testing whether the *requirement graphs* of organizations can be mapped into the *adjacency graph* of plans. The study assumes distinct activities of the organization each needing a single space, and distinct separation of the plan into spaces each able to suit the size of departments. Two interesting findings are reported: first, given a plan with a certain number of partitions, the number of fits of organizations into the plan decreases for organizations with complex relations between departments, i.e. having requirement graphs with many edges; second, given an organization with a certain number of relations between departments, the number of fits increases as the adjacency graph of the plan increases (**figure 2.17**). Steadman's model for fitting requirements

[2] The geometrical class of polyominoes is defined as "shapes made by connecting numbers of equal-sized squares, each joined together with at least one other square along an edge." (Golomb, 1996:3)

graphs into adjacency graphs, as admitted by the author, has many issues that result from the assumption of representing organizations with departments needing distinct spaces, and especially, I suggest, due to dealing with the sizes of spaces. For instance, a building with a complex *grating*[3] (Newman, 1939), despite matching the requirement graph with the adjacency graph, may not allow matching sizes due to the variance between spaces that are closely stacked with each other. There are two obvious shortcoming of the two models described above from the viewpoint of the thesis: first, the models do not consider open plans without partitions as is the case for the floorplates; and second, they are not suitable for capturing shape properties since the issue of the size of cells and the dimension of partitions has been omitted from the analysis. However, it is important to emphasize that despite issues that result from the abstraction of partitioned plans into polyomino representations, the fit between what plans offer and what organizations need is clear and simple. The strength of both models comes from the fact that the same realm of representation is used to describe both organizations and plans and the affinities between the two are thus unequivocal.

[3] "A rectangular grating, G, in the open or closed plane, is formed by drawing a finite number of segments across a square, parallel to its sides." (Newman, 1939: 91)

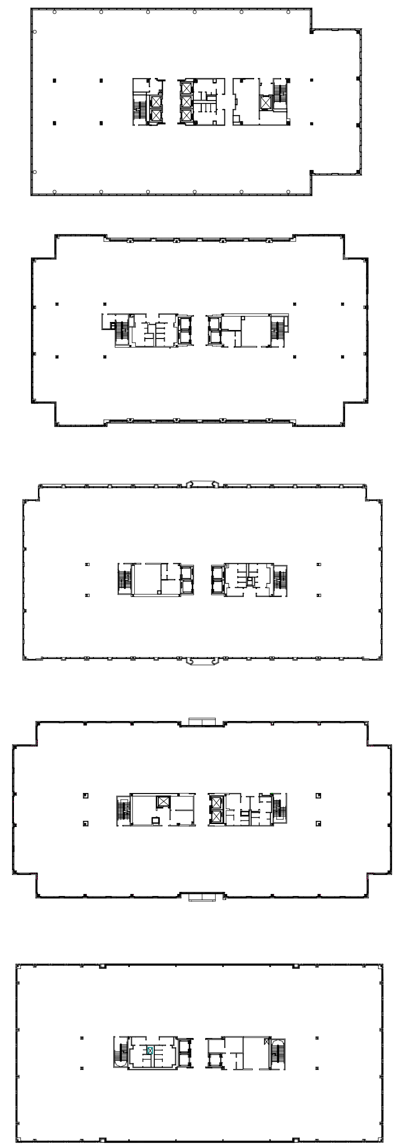
2.7 Conclusions

This chapter reviewed studies that have addressed research questions that are similar to the question addressed by this thesis about how characteristics of architectural plans affect the characteristics of layouts. The research by Duffy suggested affinities between types of shells and types of organizations based on spatial requirements of area and proportions for each subgroup or department of organizations. The strength of the model consists of the fact that the proposed typologies of both shells and layouts are based on the analysis of actual cases which are frequently encountered in architectural practice. As a result, the proposed affinities have direct applications in architectural design and planning. Shell descriptions are based on local characteristics of sub-spaces of shells, i.e. on proportions and depth of sub-spaces of shells as well as potential merging and subdivisions of sub-spaces of shells. The methodological advantage of Duffy's model is that the analysis and findings are based on comparisons between typological features of shells and layouts rather than enumeration of individual fittings between actual layouts and actual shells.

While findings are robust and global, i.e. a general picture is given for the entire organization as fitted in the entire shell; the conclusions about the degree of fitting are drawn from the fittings of departments or teams of the organization into sub-regions of the shell without considering the relations between parts of the organization. According to this model, several shells of different configurations may allow perfect fits of organizations by the virtue of kinds of spaces they contain. However, each fit in the specific shells would result in different spatial arrangements having different effects on the accommodated organization. The discussion suggested the need to understand the condition of organizations after a fitting between their required layout and a specific shell has occurred. Consequentially, the object of this thesis moves one step further to inquire not only *what* kinds of shells fit given layouts, but *how* shells affect layouts. In other words, the concept of fitting proposed here is modified to address issues of *how* parts of layouts relate to each other once realized in shells in addition to *whether* parts of layouts can physically be realized in shells.

The research of Matela and O’Hare and the study by Steadman use theoretical examples of architectural plans and hypothetical organizations to evaluate degrees of flexibility and adaptability of the fitting between the two. Due to theoretical abstractions and the nature of representations, the results are highly speculative and pertain only to fragmented architectural plans. However, these studies have a direct relevance to this thesis by suggesting methodologies that utilize equal representations of layouts and plans, in this case graphs that depict adjacency between spaces and requirements for adjacency between departments.

Due to different longevities of shells and office layouts, the model that will be proposed by this thesis will be founded on a clear distinction between the rigid component of shells and the dynamic component of layouts. This model will search for typological characteristics of shells and layouts and suggest links between shells and layouts based on fitting between types of shells and types of layouts rather than aggregating individual matches between actual pairs of shells and layouts. In conclusion, the review identified the need for proposing a model which incorporates two main features: First, it will be based on representations of shells and layouts which pertain to the same domain. From this viewpoint, the model to be proposed will resemble studies of Matela and O’Hare and studies by Steadman. Second, the model will be global due to considering all regions of shells and parts of layouts according to a configurational model.



City View, Atlanta, GA, 1999

Centura Office Building, Atlanta, GA 2000

Glen Lake Office Building One, Raleigh, NC, 2000

Hunt Crest Phase Two, Gwinnett Co. GA, 2000

1825 Century Center, Atlanta, GA, 2001

Figure 2.1: Examples of speculative offices designed by Cooper Carry Architects, Atlanta, GA during the period 1999-2001 for locations in the Southeast USA.

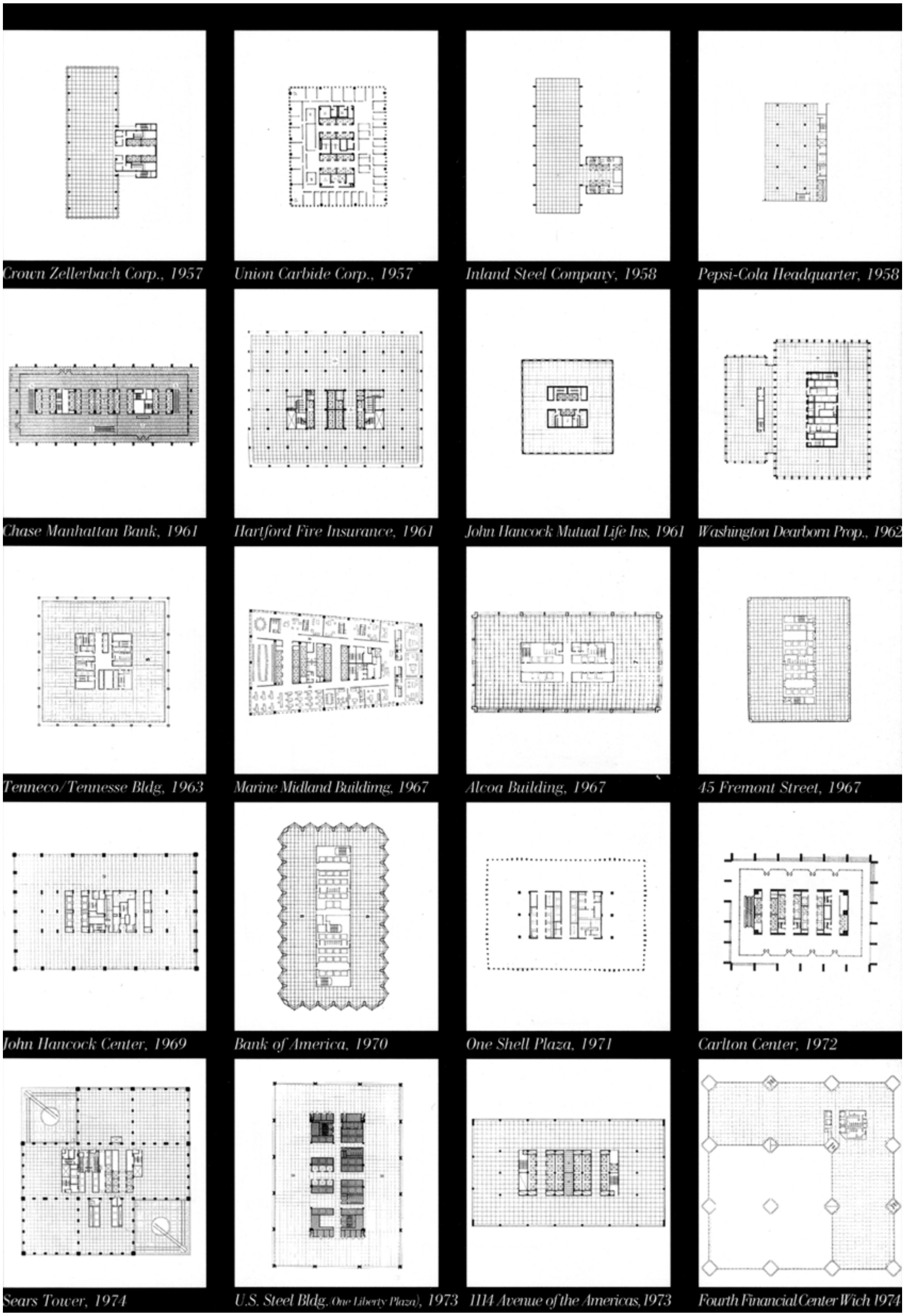
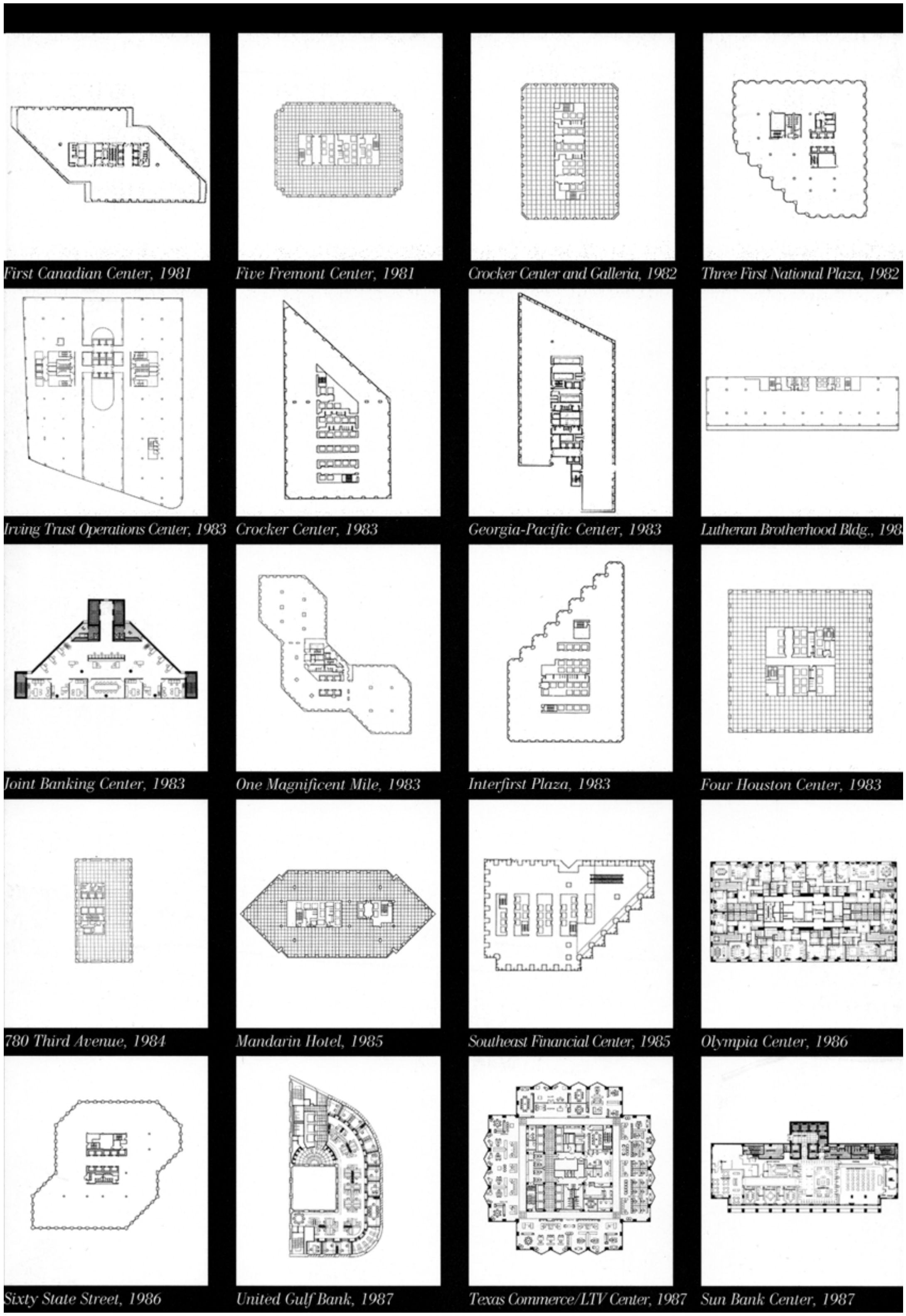


Figure 2.2: SOM Lab Hi-Rise Plan Typology Study.



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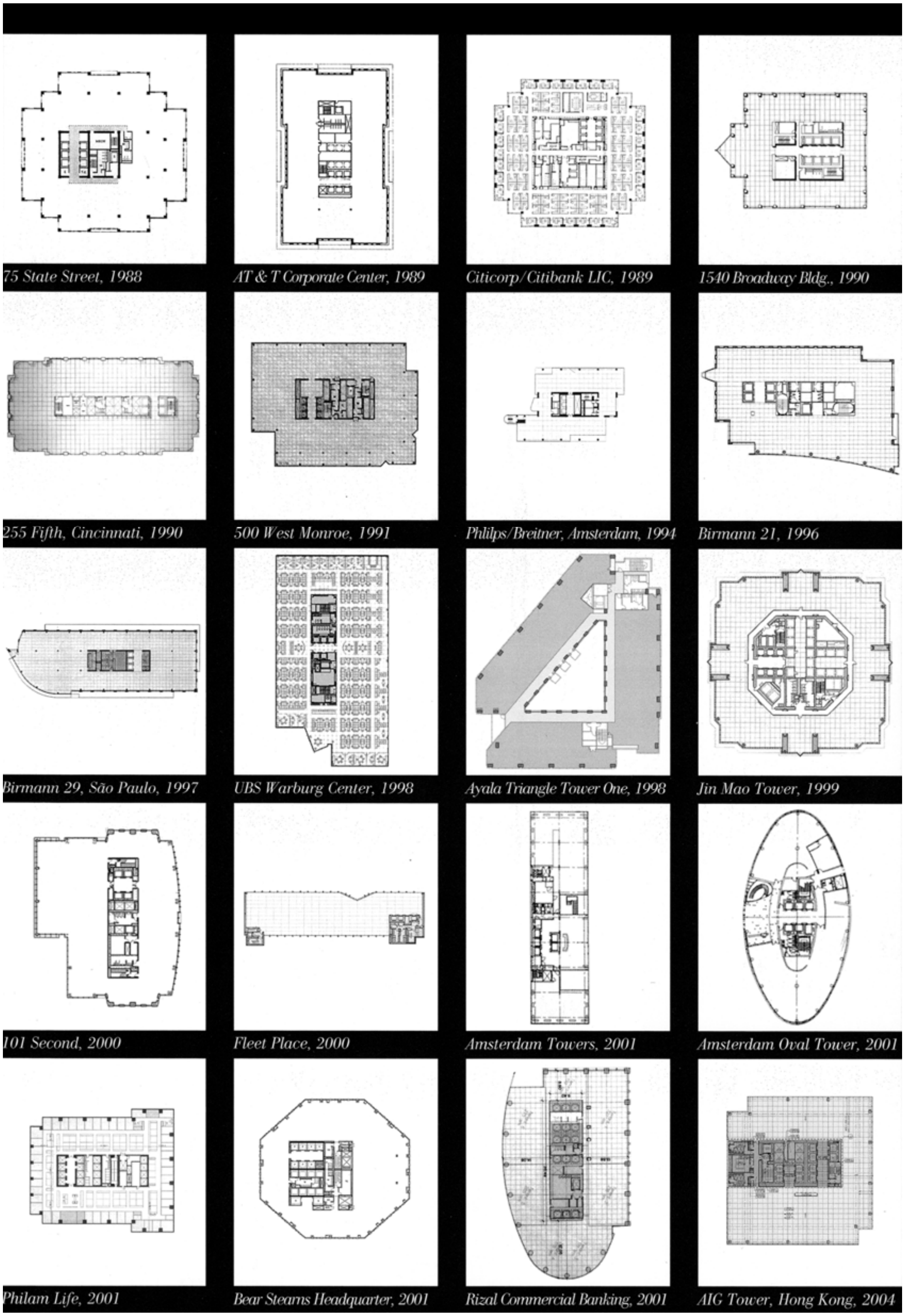

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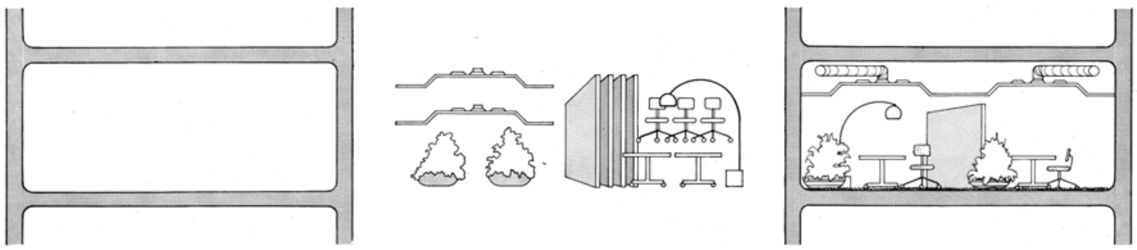


Figure 2.3: Definitions of shell, scenery and sets.

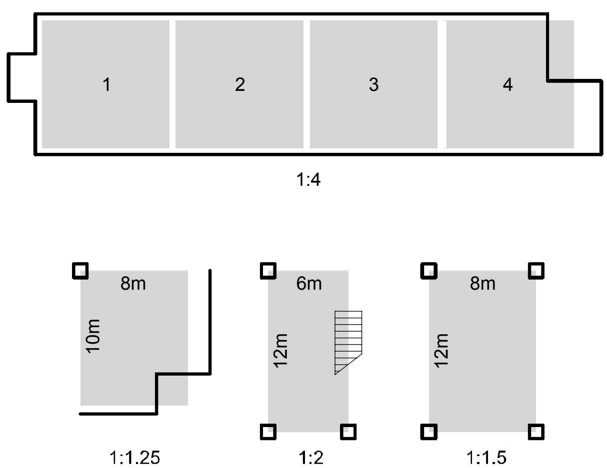


Figure 2.4: Characterizing shells and bay spaces by proportions between length and width.

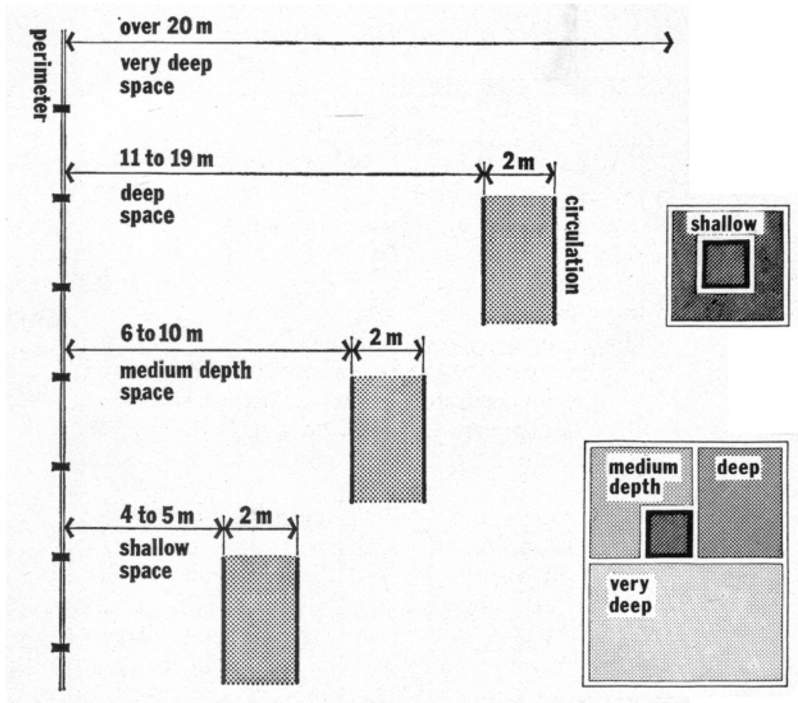


Figure 2.5: Characterizing workspace area by means of depth between core and perimeter.

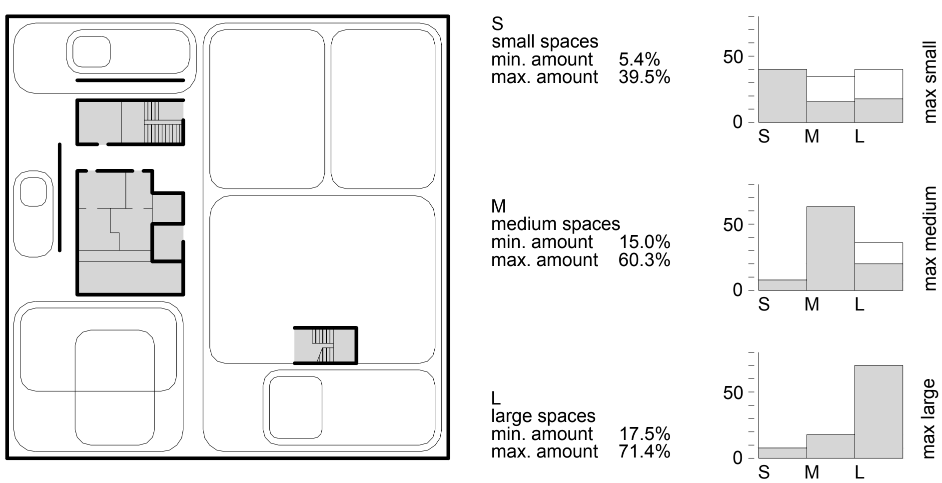
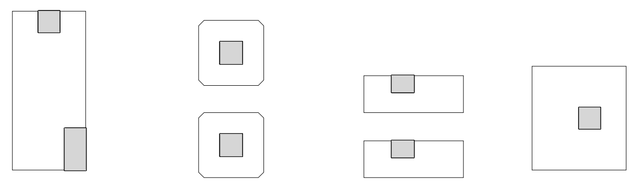


Figure 2.6: Characterizing shells by means of space stock capacity. Charts show distribution of spaces as percentages to the gross area in three cases when priorities are given to small, medium and large spaces.



	speculative type	narrow central core type	large old house type	open plan type
range of spaces provided by the shell	small medium large	small medium	medium	small large
design office	○	○	○	○
advertising agency	○	○	○	
top management	○	○		
clerical	○			○

degree to which spaces are continuous or divided from each other by the shell	spaces partially divided or fully continuous	spaces highly divided	spaces highly or partially divided	spaces partially divided or fully continuous
design office	○		○	○
advertising agency	○	○	○	
top management	○	○		
clerical	○			○

Figure 2.7: The fit between organizational requirements and shells according to: a) space stock capacity (upper rows); b) subdivision and clustering capacity (lower rows).

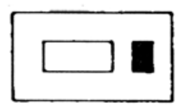
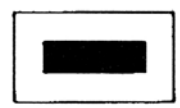
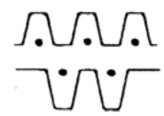
	Burölandschaft offices	Traditional British speculative offices	New ‘Broadgate’ type of British speculative office	Traditional North American speculative office	The new North European office
					
Number stories	5	10	10	80	5
Typical floor size	2,000sqm	1,000sqm	3,000sqm	3,000sqm	Multiples of 2,000sqm
Typical office depth	40m	13.5m	18m and 12m	18m	10m
Furthest distance from perimeter aspect	20m	7m	9-12m	18m	5m
Efficiency: net to gross		80%	85%	90%	70% (lots of public circulation)
Maximum cellularization (%usable space)	20%	70%	40%	20%	80%
Type of core	Semi-dispersed	Semi-dispersed	Concentrated: extremely compact	Concentrated: extremely compact	Dispersed: stairs more prominent than lifts
Type of HVAC services	Centralized	Minimal	Floor by floor	Centralized	Decentralized: minimal use of HVAC

Figure 2.8: Broadgate Project Study appraisal of building performance for different types of office.

●●● excellent
●●○ good
●○○ fair
○○○ poor

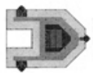
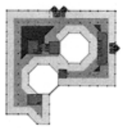
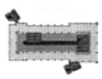
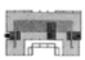
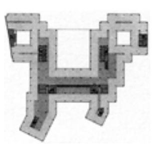
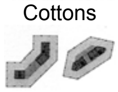
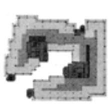
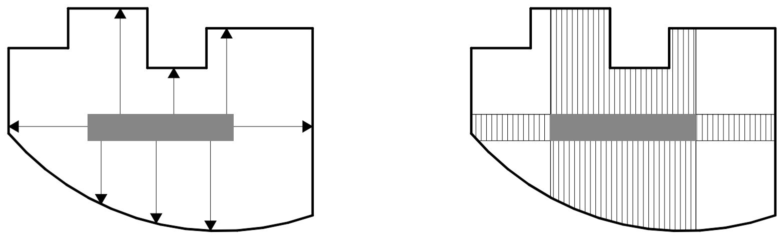
			usable area efficiency		flexibility of space			services				
	location	ease of access	whole building	office floor	cellular office	open plan	trading floor	air-conditioning	electrical services	lifts	overall rating	additional facilities
 Billingsgate	●●○	●○○	●●○	●●●	●●○	○○○	●○○	NA	NA	●●○	NA	●○○
 Broadgate 1	●●●	●●○	●●●	●●○	●●○	●●●	●●●	●●●	●●●	●●○	●●●	●●●
 Broadgate 2	●●●	●●●	●●●	●●●	●●○	●●●	●●○	●●●	●●●	●●○	●●●	●●●
 Fenchurch Exchange	●●○	●●○	●○○	●○○	●●○	●○○	●○○	●○○	●●○	○○○	●○○	○○○
 Finsbury 2	●●●	●●●	●●○	●●○	●●●	●○○	●○○	●●●	●●○	●●○	●●○	●○○
 Finsbury 3	●●●	●●●	●●○	●●○	●●●	●●○	●○○	●●○	●●○	●●●	●●○	●●○
 King William Street	●●●	○○○	●○○	○○○	●○○	○○○	○○○	●●○	NA	●●●	NA	○○○
 Lee House	●●○	●●●	●○○	●○○	○○○	●●●	●●●	NA	NA	NA	NA	●○○
 Cottons	●○○	●●●	●●●	●●○	●●●	●●○	●○○	●●○	●●○	○○○	●●○	●●○
 No. 1 London Bridge	●○○	●●○	●○○	○○○	●●●	○○○	○○○	●●○	●●○	●○○	●●○	●●○
 Ropemaker Place	●●○	●○○	●●●	●●●	●○○	●○○	●○○	●●○	●●○	○○○	●○○	●○○

Figure 2.9: Broadgate office floorplates typological data and the evaluation of buildings from the viewpoint of their suitability for being adapted to different generic types of office.



a) b)

Figure 2.10: Insufficiency of characterizing floorplates with the distance between core and perimeter: (a) the distance varies due to the geometry of perimeter, (b) areas outside the shaded cross cannot be described by this index.

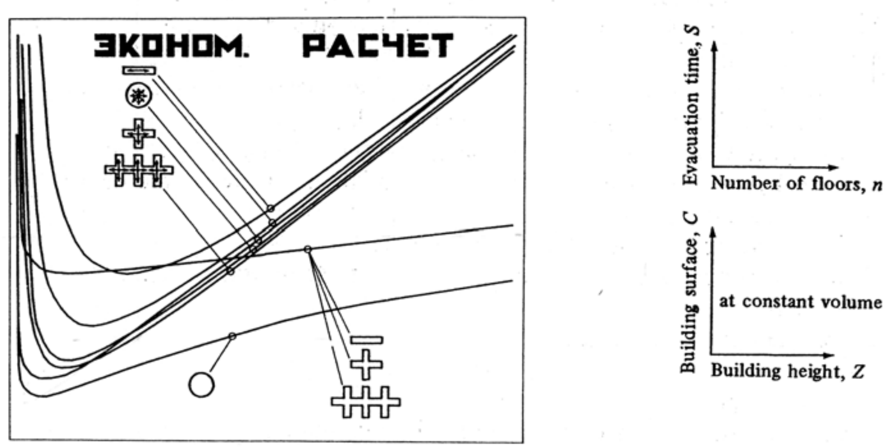


Figure 2.11: “The economic calculation”. The upper bundle of curves represents the plotting of evacuation time against the number of floors. In the lower pair, building surface is plotted against the building height, assuming constant volume.

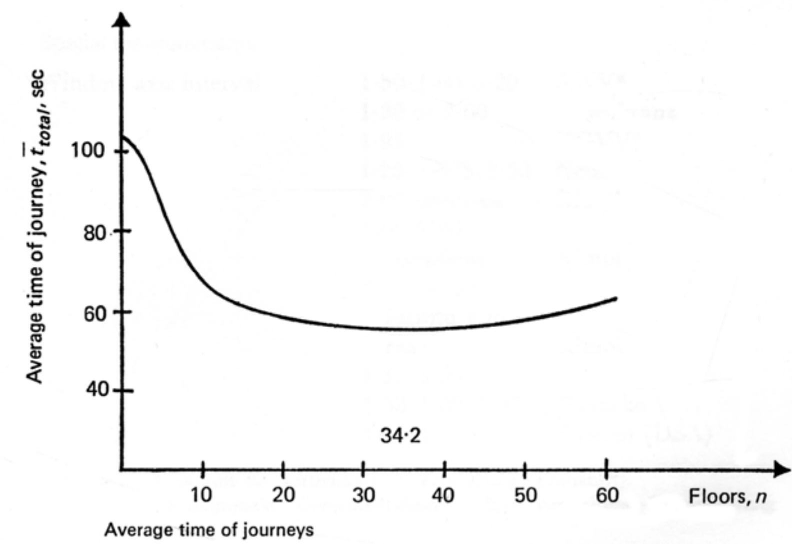


Figure 2.12: Line chart of the average number of journeys against number of floors for a constant total building area.

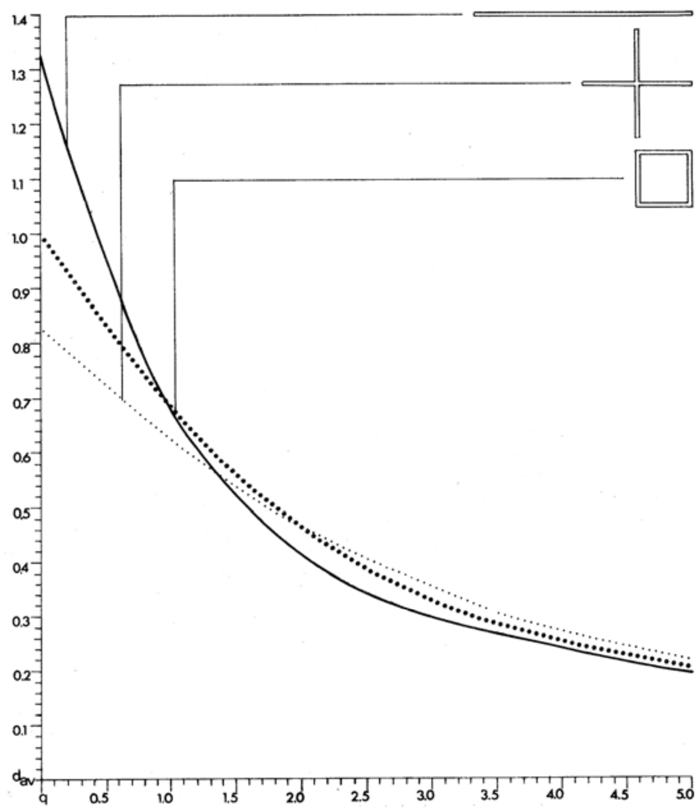


Figure 2.13: Theoretical average distances for different values of q in a slab, cross and court.

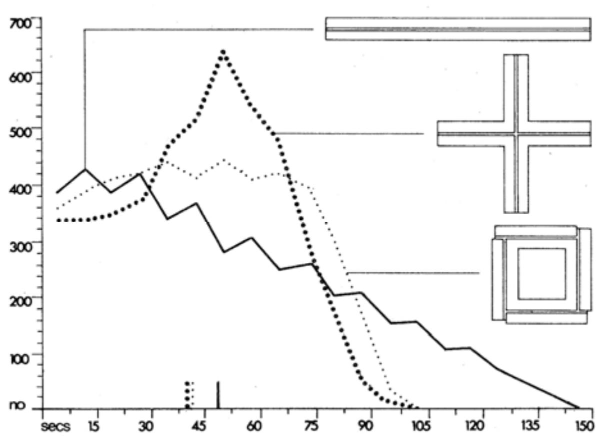


Figure 2.14: Distance distribution in one-story slab, cross and court according to Tabor (1976).

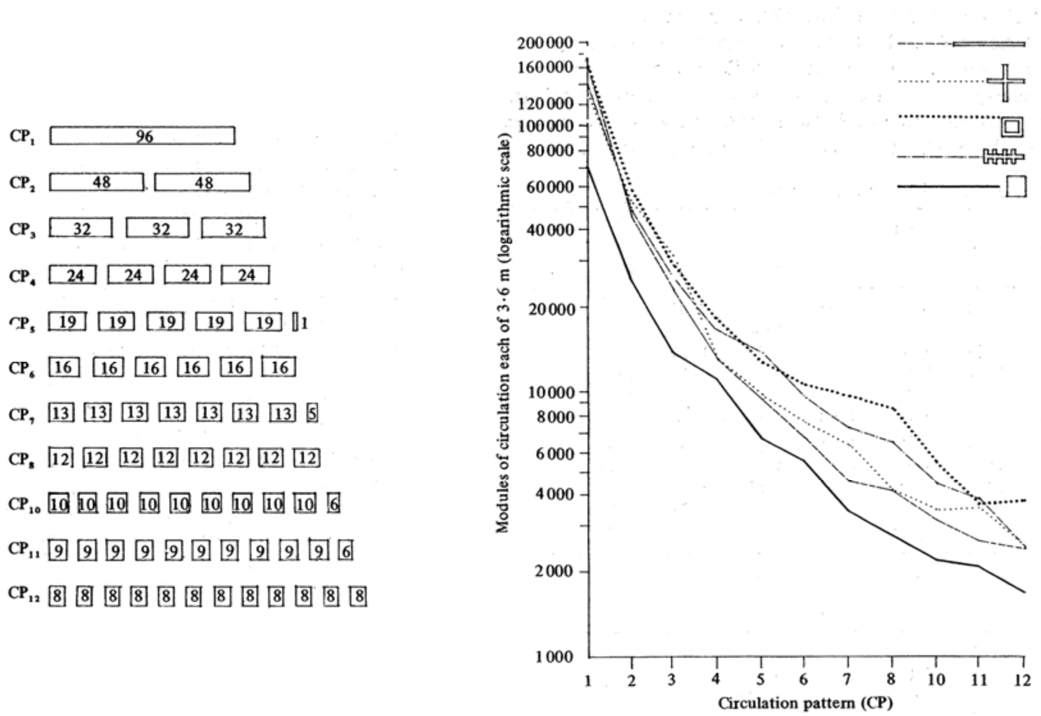


Figure 2.15: Departmental divisions for 12 theoretical circulation patterns (left), and comparison of absolute performance of single-story buildings in different building forms according to 12 circulation patterns (right).

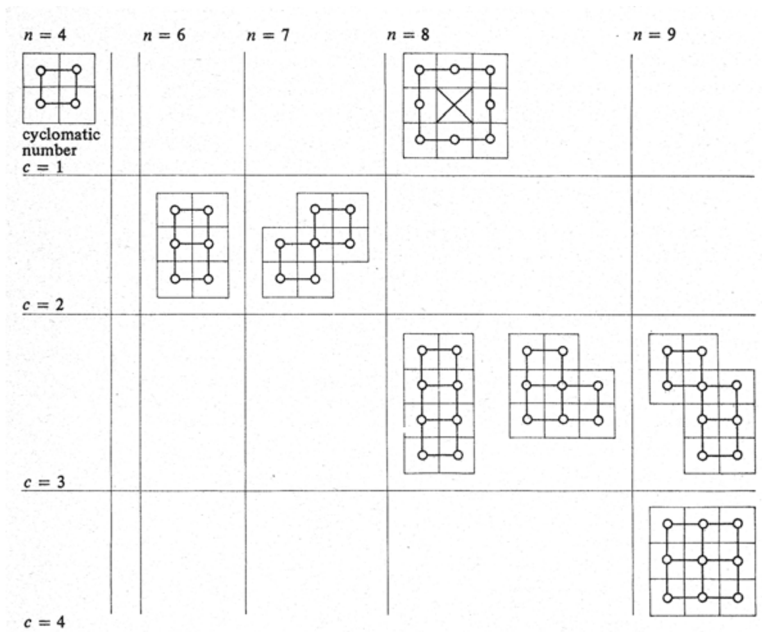


Figure 2.16: All realizations of the ‘perfectly cyclic’ graphs which can be the adjacency graphs of polyominoes, up to n=9, according to Matela and O’Hare (1976). Such graphs depict highly compact forms and offer the maximum internal adaptability.

requirements		number of allowable ways			
	number of edges	3	4	4	5
	0	24	24	24	24
	1	12	16	16	20
	2	4	8	10	16
	2	8	16	8	16
	3	2	8	4	12
	3	0	0	6	12
	3	0	0	6	12
	4	0	0	2	8
	4	0	8	0	8
	5	0	0	0	4
column total		50	80	76	132
nonzero entries		5	6	8	10

Figure 2.17: The allowable ways graphs depicting adjacency requirements of an organization (left column) can be mapped into dual adjacency graphs of rectangular dissections for n=4 (upper row). In the lower left corner below the dashed line, the adjacency requirements exceed the number of adjacencies in the plan.

Chapter Three

Space Syntax Studies on the Effect of Layout Integration on Aspects of Organizational Performance

Outline

Space syntax has been used to describe office interiors and to relate their spatial structure to patterns of space use, including movement, co-awareness, encounter, interaction and the creation of interfaces between different organizational groups, roles and statuses. A number of studies have demonstrated that Integration of layouts correlates strongly and significantly to observed levels of movement and perceived co-awareness and co-presence among various groups and individuals in office organizations. This chapter reviews the main theorems and concepts of space syntax, the representation with linear maps, the concept of configuration and the measures of Depth, Integration and Connectivity. It uses findings from space syntax research on office environments to support the choice for using the Integration of layout circulation as a key descriptor of office layouts.

3.1 Main definitions and measures of space syntax

This section briefly reviews the fundamental propositions, theorems, representations and measures of space syntax, focusing particularly on the measure of Integration.

3.1.1 Theorems

Space syntax refers to the set of analytical techniques and the body of research that has developed upon theoretical ideas first presented by Hillier and Hanson (1984) in the 'Social Logic of Space'. The central question to space syntax studies is how spatial arrangements influence patterns of social behavior and whether built space inherits a social logic. The theory addresses the understanding of built environment from the viewpoint of society that produced it as well as the effects of space on conditioning social relations. Hillier (1989) identifies three types of laws necessary for understanding the built environment: first, laws for the generation of urban and architectural objects themselves; second, laws of how society uses and adapts the laws of space to shape certain social relations; third, laws of how space affects on society. The central proposition of space syntax is that laws between society and space are negotiated through 'spatial configuration' as an objective feature of spatial complexes. Peponis and Wineman (2002), in their review of the space syntax literature, identify two key theorems to illustrate two contrasting ways in which space works socially.

> The first examines linear spaces, such as streets in urban areas or circulation in building, and the paths of movement along those spaces. This theorem suggest that, if the building or urban area is considered as a system that carries movement from every space to every other space within the system, certain spaces, those that are most directly connected to every other space in the system, will tend to attract higher densities of movement. Put more simply, more direct universal accessibility implies a higher probability that a space will be used for movement. (Peponis and Wineman 2002: 271)

The first theorem describes an objective property of spatial complexes, that of generating movement independent from social rules or programmatic functions of organizations, but dependent on the spatial configuration. Space is thus given a *generative* role for producing movement and social aspects related to it. According to Peponis and Wineman, there are three derivations of the first theorem, of which the first is directly related to this thesis - the distribution of movement is a function of spatial configuration (Hillier, Penn et al. 1993).

> “The second theorem addresses the underlying spatial relationships that come into our common definition of building types. For any given building type there are some labels that are typically used to describe its component parts by activity (e.g., ‘dining room’), social rule (e.g., ‘private room’), or function (e.g., ‘reception’); it is intuitively known, however, that a list of component spaces is not a building. Buildings set component spaces into particular patterns of relationships. The precise patterns vary from design to design. The second theorem suggest that invariance resides in the statistical tendency for some labeled spaces to be more directly accessible, in the plan as a whole, than other labeled spaces.” (Peponis and Wineman 2002: 272)

From the viewpoint of the relation between space and society, the theory of space syntax is based on the principle that certain patterns of human behavior are strongly linked to the underlying structure of space, which is revealed by analyzing features of its constituent elements or units with regard to other elements thus capturing patterns that are purely relational among elements. This principle thus demands two basic conditions: first, identifying the social significance of properties of relational patterns; and second, recognizing the translation of a spatial system into relational patterns. Both the partitioning of spatial complexes into elementary units and the establishing of relations among units are aimed at capturing space features that have a behavioral significance, without, however involving behavioral data per se. Correlating the behavioral data with the spatial data is used to justify our choice for features of relational patterns from the viewpoint of their social implication. The wide variety of space syntax analytical techniques springs from the diverse positions on representing space into elementary units and the mapping of different interrelations.

3.1.2 Linear Map Representations

The representation of space with linear maps is one of the earliest space syntax techniques based on discrete elements. Linear maps, or axial maps, are the set of the longest and fewest lines of sight and access that can be drawn over elongated spaces such as the case of urban systems or the circulation in buildings (**figure 3.1**). The linear map representation is based on our experience of moving in a linear direction and thus captures the structure of space that is associated with movement. This representation is the most widely used due to depicting characteristics of space that are shown to affect the potential for various aspects of human behavior over and above representations with convex break-up and isovists (Benedikt 1979). Representations with all-line maps are elaborations of linear maps where all possible lines (according to a fine grid of points) are drawn over the spatial complex (Penn, Desyllas and Vaughan 1999; Spiliopoulou and Penn 1999). The syntactic analysis of work environments has widely used linear map representations, consequentially; the emphasis of this review is given to the representation with linear maps representing the internal circulation in offices.

The linear map, or axial map, thus defined, is based on a fundamental assumption that is explicitly discussed by Hillier and Hanson (1984) but not always remembered in subsequent literature. The assumption concerns treating a spatial system as made up of two kinds of entities only, primary cells (the equivalent of workstations, meeting rooms or other primary use spaces in this thesis) and public open space (the equivalent of corridors in this thesis). What this description does not take into account is the possible formation of higher order entities, such as neighborhoods (or workgroup areas in this thesis) whose relationship needs to be considered in its own right. Thus, one could describe a neighborhood according to the statistical properties of the lines that comprise it, much as one could describe a group work area according to similar statistical properties. What this still does not take into explicit account is the possibility that the relationship between such higher order units is the key to the formation of the layout in the first place. The thesis does not propose to advance a theory of nested syntactic descriptions. Rather, it will proceed on the assumption that the description of a spatial system according to the two kinds of elements, primary units and linking circulation is likely to be fundamental to any future theory of nested descriptions.

Modular representations of spatial complexes are a later addition to space syntax techniques. A review of these techniques, as related to the descriptions of shape, is given in Chapter Four.

3.1.3 Graphs

Similar to other space syntax measures, the calculation of Integration, which will be discussed in the next section, is based on relations between spatial units which are described by properties of *graphs*. Graphs are mathematical representations that consist of two parts: elements representing entities or objects, termed graph nodes or vertices; and links between vertices representing relationships between these elements, termed graph edges (Harary 1969; Steadman 1983). In the light of various space syntax representations, graph nodes depict the spatial entities of convex spaces, axial lines, isovist polygons or tessellated units of spaces, while graph links represent specific relations of connectivity, overlapping, adjacency, or co-visibility. Graphs are diagrams of pure relations.

> "Because it (the graph) is a map of pure relations, in which elements (or nodes) have no attributes apart from being connected to others, graph measures naturally measure extrinsic, or nonlocal, properties of elements. Even the simplest measure of a node, the connectivity (or degree) of the node, expresses not an intrinsic property of the element which it would retain if disjoint from the system." (Hillier, 1999: 189)

The key concept of *depth* is founded on the step distance between two vertices of the graph, i.e. the shortest number of links between two nodes. The Depth of a node is defined as the aggregate of Depths of the node to all other nodes in the graph.

3.1.4 Configuration

Depending on the composition of links in the graph, nodes are differentiated between each other with respect to the values of Depth, i.e. the total number of steps needed to reach to all other nodes in the graph. Hence, a graph would look different when viewed from different vantage points of different nodes, i.e. when justified from the node in consideration (**figure 3.2**). The graph thus forms an entity composed of nodes that are differentiated to each other from the viewpoint of their Depth to the whole system. Adding or removing a single link between two nodes apart from the local impact on their Depth values, has an overall global implication of affecting the Depth of all other nodes in the graph, hence the total depth of the graph. The three concepts: depth between nodes; the part-whole relationship between nodes and the entire graph; and the local-to-global logic of links between nodes describe in combination the notion of *spatial configuration*.

> "Configuration is defined in general as, at least, the relation between two spaces taking into account a third, and, at most, as the relations among spaces in a complex taking into account all other spaces in the complex. Spatial configuration is thus a more complex idea than spatial relation, which need invoke no more than a pair of related spaces. The theory of 'space syntax' is that it is primarily – though not only – through spatial configuration that social relations and processes express themselves in space." (Hillier, Hanson et al. 1987: 363)

3.1.5 Integration

The measure of Integration is based on the concept of *depth* and is calculated by a simple algebraic function that relativizes the Depth of a node by the overall number of nodes in the system, thus taking off the effect of size and enabling comparisons across samples of buildings or samples of cities. In the earlier space syntax research (Peponis 1985), the measure was termed *Real Relative Asymmetry* RRA (**figure 3.3**). Due to the relativization, Integration varies around 1. The research at the Space Syntax Laboratory of University College London reports that Integration of linear maps of circulation for an analyzed sample of office layouts ranges from 0.5 to 1.5 (Penn, Vaughan 1995), and if only main circulation spaces in the sample are analyzed, the measure ranges between 0.602 and 1.063 with a mean of 0.817 (Grajewski, Hillier, Penn et al. 1994). A node with a high value of Integration, or else an integrated node, has a low Depth in relation to other nodes in the complex, whereas a segregated node has a greater Depth. The low Depth or high Integration is indicative of centrality of the node in relation to other nodes in the complex. Therefore, the measure of Integration quantifies the *syntactic centrality* of a node in a complex. The measure is founded on a global logic for both cases when it characterizes local features of a particular node, and when it characterizes the global features of the entire system. Hence, it is possible to discuss integrated corridors as well as integrated layouts. The calculation of Integration is normally based on the Depth from one node to all other nodes in the system, which is termed as Integration (radius n). The calculation of local Integration, (radius 3) takes into account the Depth resulting from adjacent graph nodes up to three steps away. The measure of Integration Interface gauges the extent to which a spatial system differs from global to local viewpoints.

Integration, thus defined, does not take into account metric distance, corridor width, visual field, and 3-D spatial relationships, all of which are important in office design. Furthermore, integration is not necessarily a positive thing that is always desirable. For example, while integrated spaces are often required to generate high levels of interaction, segregated spaces are best suited for individual work processes that require autonomy and low interaction.

3.1.6 Connectivity

Connectivity quantifies the local property of connections of a node to its immediate neighbors. It counts the number of graph links of a node. The measure is based on a local logic both for single elements and entire systems.

3.2 Space syntax research on the effect of layout integration on organizational performance

A substantial body of space syntax research on work environments has revealed strong and significant correlations between layout integration and interaction, encounter, and co-presence between individuals and teams, which in turn have been attributed to performance aspects of organizations. It has been shown that behavioral aspects spring from and take advantage of the pattern of movement generated by the spatial configuration. These studies have suggested the existence of significant links between spatial features of layouts and behavioral aspects in organizations, supported by the first corollary of the movement theorem in one hand, and by a number of sociology studies that report the benefit of ties, contacts and interaction for the generation of knowledge and creativity at work, in the other.

Social ties have been attributed to the enhancing of creativity of teams and individuals that are well connected to teams and individuals from other disciplines. Findings of two studies have supported this claim: The first research from Allen (1977) on communication and innovation in research and development (R&D) organizations in engineering has suggested that improved communication among groups was strongly related to work performance (**figure 3.4**). This is more evident when the interaction occurred between members of teams that are not programmatically related in the organization, who supplied teams with information from outside necessary for the group performance. The study by Granovetter (1982) reports that any individual has a network of *strong ties* of close friends and a network of *weak ties* of acquaintances that do not normally know one another. Weak ties act as bridges between clusters of strong ties and are primarily responsible for the dissemination of knowledge and information.

The link between spatial and behavioral variables by no means has a cause and effect format. The theory of space syntax is founded on the paradigm which postulates that social encounters have a spatial logic and spatial arrangements have a social logic. While explicitly distancing itself from the paradigm of cause and effect between environment and behavior (Hillier and Leaman 1973; Hillier and Hanson 1984, Hillier, Hanson and Graham 1987), syntactic research seeks to understand relationships between patterns of space and patterns of encounter by empirically investigating space as a relational pattern in itself and observing its use for the purpose of establishing regularities in the pattern of use. The spatial structure of layout is one of the many aspects that affect the organization's performance, mainly on the realm of creating the potential for the generation of particular interfaces in the building. Its main effect is at the level of the group and not the individual.

> "…The strong effects that have been found relating building design to the construction of researcher's social networks are system effects. That is they relate most strongly to the organization or building as a whole, and cannot be attributed as deterministic effects for any single individual." (Hillier, O'Sullivan, Penn et al. 1990: 31)

Similarly to urban systems, large buildings are likely to generate movement according to the spatial features over and above the functional and organizational program. Hillier and colleagues suggest that in large buildings…

> "(Space) is adding the generation of a social field that is unstructured, but which, like a settlement, acquires a predictability and reproducibility – and therefore a social identity – through adapting its spatial organization to nurture and organize this emergent phenomenon. The true function of large buildings in our time is, we believe, to create these emergent social organisms." (Hillier, Hanson and Peponis, 1984: 70)

However, the relationship between spatial layout and patterns of movement and interaction in large buildings becomes more complex in comparison to urban environments due to the fact that functional requirements and programmed interactions between members of organizations play their roles alongside the effect of space. For instance, in the case of two office departments that are both spatially segregated and functionally related, high levels of movement between them would be attributed to programmatic aspects of the organization rather than to the spatial characteristics of the layout.

One of the earliest space syntax studies on work environments is the pilot research on a sample of seven UK organizations and their offices (Hillier and Grajewski 1987). The study is aimed at testing the hypothesis that relates patterns of space use with spatial features of the work environments based on a three-faceted model comprised of: First, the *organization*, which is defined as a system of roles, tasks, and statuses without invoking spatial issues of their environments; Second, organization's *deployment in space*, which is profiled and quantified according to three categories of observed behavioral patterns of movement, talking and working; Third, *spatial features of layout*, which are analyzed using Integration, in addition to other measures of *differentiation* of axial lines and convex spaces, *k-effect* and *s-effect*. The *k-effect* (Hillier and Hanson 1984), measures the degree to which axial lines pass through the set of spaces identified as convex. The s-effect, indicates the degree to which the complex is organized into fewer or more space-time frames for a person moving around it. The study questions at what extent organizational factors need to be invoked to explain findings on the relation between spatial layout and the use of space for work. In order to test the hypothesis, the study constructs a model of the spatial aspects of productive work and organizational objectives consisting of the degree to which individual tasks are identifiable to team tasks, the degree that team tasks are regulated and do not involve unprogrammed interaction, the degree to which tasks require the cooperation between teams as well as the degree to which the organization seeks to build a corporate identity. The analysis of layouts and of patterns of space is therefore aimed at revealing the spatial characteristic of this model by proposing space use types and spatial layout types. The study reports that of the syntactic measures, Integration is the best predictor of movement patterns (r=0.59), whereas, two distinct correlations between Integration and levels of observed movement coincide with the bifurcation in the sample from the viewpoint of high and low *occupation densities*. In addition, the study finds that workers occupying more segregated workplaces travel farther than those occupying more integrated locations. In conclusion, the study proposes a three-fold hypothetical model that correlates in pairs characteristics from organization profiles, their space use and layouts (**figure 3.5**).

The intricate balance between the effect of spatial aspects of layouts and programmatic aspects of organization into levels of human activity in large buildings shifts in accordance to the nature of the *program* in buildings. In *weak program* buildings, spatial configuration affects movement and encounter more than in *strong program* buildings, in which by contrast, the programmatic aspects of the organization exert a greater influence. Strong programs exist when buildings should achieve interfaces among inhabitants and visitors that are based on a long list of well-specified and unambiguous rules and procedures. Buildings with weak program construct interfaces that have the nature of a *short model* (Lévi-Strauss 1967). In this case a great deal of encounter results from the way laws of space affect movement rather than from programmed and articulated social procedures (Hillier, Hanson and Peponis, 1984).

Hillier and Penn (1991) report strong and significant correlations ($r=0.83$, $p<0.001$) between Integration of axial lines drawn over the layout circulation of a London daily newspaper and the density of space use measured by the number of moving people. Integration values are strong predictors of the levels of movement that in this case reflects the by-product of moving through routes from all workspaces and equipment to all others (**figure 3.6**). The layout circulation, similar to urban grids, has an integrated core that provides shallow connections to the outside and to all the peripheral workspaces. It, thus behaves according to a generative mode by structuring a dense and random pattern of encounter, without reflecting a preexisting organizational agenda. The building exemplifies a weak program and a short model case due to the unprogrammed encounters between staff members and the ever-changing priority between groups according to the nature of the developing news. The newspaper office has a dynamic structure and a shallow hierarchy where functional requirements of assigning jobs and temporarily designating teams depend heavily on the generation of social relationships stimulated by the spatial setting. In contrast to the strong models of courtrooms or medical office, the newspaper organization depends much more on the spatial setting for generating encounters that otherwise might not exist outside it.

In the same study, the comparison of two UK research labs reveals different spatial structures in which connections between departments or cells occur in one case shallow or near the main circulation space, and in the other deep or close to the building perimeter. The pattern of space use has been recorded by direct observations and categorized in four kinds of activities: *contemplative*, *practical*, *interactive* and *movement*. The study suggests that the two labs differ radically from the viewpoint of where the interaction activities are located. In the one where interaction occurs deep and away from the global movement in the main corridor, communication reinforces local ties between members of teams at the expense of the larger group. In the second lab where interaction occurs shallow and close to the main circulation, communication tends to shift between a local team to other groups in a global scale. In the second case, the layout has the potential to work *generatively* creating ties among members of different departments.

In contrast to the findings by Hillier and Grajewski (1987) discussed above, Serrato and Wineman (1999) suggest that neither *occupation density* nor *visual density* are strong predictors of communication rate. This study compares two research and development labs: Lab A where the spatial layout corresponds to the organizational description, and Lab B where workers from different groups of knowledge areas are interspersed and are spatially co-located. The behavioral data is gathered by randomly paging selected participants during a one month period and recording their activity, location, and the nature of interaction in which they are involved. The spatial analysis utilizes conventional axial line maps drawn over layout circulation space. The study reiterates the finding of Hillier and Penn (1991) about the local-to-global integration interface being the stronger predictor of *interaction* among scientists ($r=0.70$, $p<0.0001$).

The analysis of seven research laboratories in the UK carried out by the Space Syntax Laboratory for the British Department of Education and Science (Hillier, O'Sullivan, Penn et al. 1990) looks for effects of spatial layout on space use and movement, consequently on contact networks, and the degree to which these contacts are useful. As it was discussed earlier, this logic takes for granted that contacts, especially those outside one's group, are beneficial for the generation of knowledge. The study relies on three main bodies of data: First, features of spatial layout measured by axial Integration in local scale (radius 3) and the global scale of the entire building as well as the efficiency of layout given by the bench length per unit of area; Second, patterns of space use characterized by observed through movement, local movement, talking and bench working; Third, density and perceived usefulness of network contacts recorded by questionnaire citations. Of the many complex relationships reported, few are of particular interest to this discussion: First, as the layout becomes more efficient, the local integration resembles the pattern of the global integration as indicated by values close to 1 of the proposed measure of *integration interface* (measured as the ratio of the local integration to the global integration). The local integration goes against the efficiency, whereas the global integration correlates well with it. Thus, simple, shallow and spatially integrated layouts are also more efficient; hence the effect of spatial efficiency on integration is 'designed in' as an attribute of dense layouts. Second, while no good correlations are found between direct spatial variables and the density of contacts, the measure of integration interface correlates strongly and significantly with both useful contact densities and with the degree to which contact networks are converted into useful ones, (**figure 3.7**). Therefore, to the extent that the patterns of local system resemble those of the global system, useful contacts outside the immediate group will be increased. While the degree to which contact networks are found to be useful contacts correlates with the spatial integration and the density of occupation of space, it does not have a relationship with the density of the networks themselves.

The study of Grajewski, Miller and Xu (1991) compares behavioral observations against the spatial analysis of the office layout of the Swedish Council of Building Research (BFR) in Stockholm. The spatial structure is studied by means of axial analysis; the behavioral data are gathered by observations of movement and occupation and the questionnaire citations of contacts among individuals in the organization. For the overall organization, in contrast to high levels of communication between individuals and teams operating in one floor, very low interaction is found between teams located in separate floors. The syntactic measure of

Integration is shown to be indicative of various spatial conditions in the building and consequently different levels of interaction: highly integrated central areas for each floor stimulate interaction within the floor, while the poorly connected vertical circulation and common areas in the context of the whole building explain the lack of interaction between floors. The Integration correlates with external citations (r=0.876, p=0.0569) (**figure 3.8**). The second descriptor of layout, the *rate of occupancy*, which takes into account the number of people working in the floor in a given time, is suggested to explain high levels of interaction for dense layouts of Administration, Director's Office, Secretariat and Publishing groups and low interaction in the case of sparsely occupied Research groups (r=0.977, p=0.0041) (**figure 3.9**). From the perspective of generating weak ties and exchanging information between different teams, the BFR Building performs badly due to both highly integrated and introverted character of individual floors with regard to the building as a whole.

Penn and Vaughan (1995) investigate the existent pattern of space use and its effect on communications between workers as a benchmarking for the refurbishment design schemes for SmithKline Beecham Ltd., UK by BSRF Architects. The spatial layout is analyzed with linear maps while space use observations for a convex space are attributed to the axial lines which pass through it. The study corroborates the findings reported earlier that layout circulation integration is the best predictor of the *movement patterns* (**figure 3.9**). The global Integration is found to correlate with the *observed talking* as well as with the locations of workspaces of those individuals in the organization considered to be useful by people with whom they did not work (r=0.793). This is supported by the phenomenon of *recruitment* that happens when an individual is moving through an area outside his group and is regarded as available for interaction by individuals working along his path (Backhouse and Drew 1992). As more integrated environments generate more through movement, more people are likely to get recruited for interaction outside their immediate groups from others whose workspaces are in visual contact with the trajectories of movement.

A later study by Penn, Desyllas and Vaughan (1999) profiles in a detailed manner the spatial cultures of two British organizations, an energy utility and an advertising company. It is suggested that Integration coupled with *spatial differentiation* provide the range of layout conditions needed for generating a successful climate of communication and creativity in organizations. The findings reinforce several of the points discusses earlier: First, like in most large buildings, Integration is a reliable predictor of levels of movement. In the second building, when observations in gates to dead-ends are excluded, the correlation is strong and significant (r=0.959, p=0.0001); Second, the Integration predicts the levels of frequency of encounter between business units (r=0.898, p=0.0001); Third, the frequency of an individual being seen, correlates with him being perceived as useful from other members of the staff (r=0.877 and r=0.865); Fourth, the usefulness of someone to those who do not work with him is related to the average spatial Integration of the zone where the person is located (r=0.928, p=0.721). The study considers the pattern of movement as a key *resource* afforded by the building to a particular workplace location and reveals that interaction is both dependent on the overall number of people available in a space (r=0.966, p=0.0001) and it is spatially differentiated according to the degree that presence or absence of people in general is spatially differentiated (**figure 3.10**). Hence, spatial differentiation is attributed with the quality of the *facility* that modifies and controls the use of interaction between people depending on the nature of tasks in the organization.

Spatial characteristics of layout not only impact levels of movement and face-to-face interactions, but as Spiliopoulou and Penn (1999) suggest, they have an important influence on the generation and practice of electronic forms of communication in cases when employees have similar seniority status and their communication is required by the management task. The study analyzes the organization of Wolff Olins Corporation, based in London, UK, occupying an open plan layout in three floors of a building with the aim of weighing the complex balance between spatial factors, managerial models and virtual means of communication in contributing towards the generation of interaction among staff. The method of study is based on the spatial analysis using all-line maps (where Integration is calculated based on the connectivity matrix of all possible lines of sight and permeability in the floorplate), space use observation, description of the management structure, as well as the study of networks of email and telephone logs among staff. While no strong correlations are found between Integration and observed movement (recorded through gate observations) in the scale of the whole building, separate floors demonstrate very strong and significant correlations instead (**figure 3.11**). The study shows that electronic communications are either used to reinforce existing relations created due to spatial proximity and connectivity or to overcome distance and spatial isolation. While no strong correlations are found between levels of global Integration and density of electronic communication in general, trends have been observed in the density of electronic communications that coincide with the degrees in which workplaces are spatially differentiated: people sitting in segregated areas tend to use more often telephone and e-mail to overcome the lack of physical interaction, while people sitting in integrated areas form social groups and communicate extensively via e-mails. It is argued that spatial isolation and distance work in two different ways: either by forcing people to use e-mail to overcome separation or by reducing interaction to the minimum.

Organizations use different strategies to relate the generic laws of space to their management models. Rashid and Zimring (2003) study the management models of three government organizations in the USA by means of interviews and observations and analyze the linear map representation of five office layouts pertaining to them (**figure 3.12**). Five organizational constructs are used to profile organizations: *communication*, *control*, *territoriality*, *privacy* and *status*. Layouts are characterized by five descriptors: shape of circulation core, group territoriality, spatial hierarchy based on accessibility, rank orders of local and global accessibility of space categories, and orders in geometry and axial structure (**figure 3.13**). The study demonstrates how spatial characteristics of layouts support the organizational constructs: Organizations that encourage interaction use layouts which are organized along few linear circulation routes, layouts that group workspaces and decrease travel distances between them, as well as layout with high interconnectedness of the axial structure. Territoriality, privacy and status are associated with segregation and few connections of space with the main circulation system.

3.3 Conclusions

The review of space syntax research on work environments has shown evidence of the effect of the spatial features of layouts on aspects of behavior of individuals in offices. These effects have the nature of the group effects since they display consistency in the larger scale of the group and the entire organization and not on particular individuals. The link between physical features of space and aspects of behavior has a probabilistic nature and is based on the potential of the first to inflict changes on the second, without, however, having a causal effect of the nature proclaimed by deterministic theories in architecture. The relationship between layout and behavior in work environments is complex and by no means direct. The studies reviewed in this chapter have shown that the managerial model used by the organization is the intermediate variable that influences the outcome of behavior between members of the organization over and above the spatial features of layouts. The seminal research of Hillier and his colleagues (Hillier, Grajewski and Peponis 1987) has proposed a three-layered model that builds relationships between spatial features of layouts, organizational profile and patterns of observed behavior. However, the object of this review has been to identify spatial descriptors of layouts and aspects of behavior in work environments that have shown consistent dependencies across many studies, leaving aside the issue of how and at what extent the managerial profile of organization influences the link between them.

Interaction between staff has been considered to be crucial for the work performance in organizations, especially when communication occurs between individuals from teams that are not functionally related (Allen 1977; Granovetter 1982). The importance of interaction has been attributed to the exchange of information, utilizing existing expertise and resources, to decision-making and to the enhancement of creativity at work and to the satisfaction with the job (Brill 1984). Over and above the communication by electronic devices and by mail, the face to face interaction and communication between teams and individuals has a direct spatial dimension and relies on the levels of movement and on densities of people available for interaction. Backhouse and Drew (1990) have demonstrated the process by which the individual is considered as available for recruitment when he is moving outside his area of work. Movement of people outside their immediate areas of work and the number of people present at a given time in a given space have been therefore ascribed with the potential for generating interaction beneficial for the performance of organizations.

One of the major contributions of the space syntax theory has been to prove the dependence of levels of movement from the spatial configuration in built environments. Especially for large spatial systems, the through movement in a space, of the nature of probabilistic trips between locations throughout the system, is dependent on the pattern of connections of that space not just to the immediate spaces but to the whole system in a relational manner. The measure of Integration quantifies exactly the feature of spaces to be syntactically centrally positioned in the system or else to be shallow from everywhere else. For large systems, including office environments, space syntax research has shown evidence of strong and significant dependence of the observed movement on the degree of spatial integration. Hence, while Integration predicts levels of movement, the interface of workspaces to the integrated spaces in the complex, determines the degree and the location of interaction between workers. In general, the density of occupation in layouts affects Integration; denser systems are also more integrated.

This chapter concludes that the space syntax research on office environments demonstrates that the Integration of layouts can be used to predict levels of interaction and usefulness of individuals in organizations to the degree that they are derivable from features of layouts. From the complexity of factors that affect the performance, the model offered by the space syntax research sets aside the effect of spatial layout and predicts its potential for generating interfaces with direct consequences on the organization performance. Integration of layout circulation will be used to evaluate and characterize in a comparative manner actual layouts as well as hypothetical layouts which will be applied on actual and theoretical floorplates.

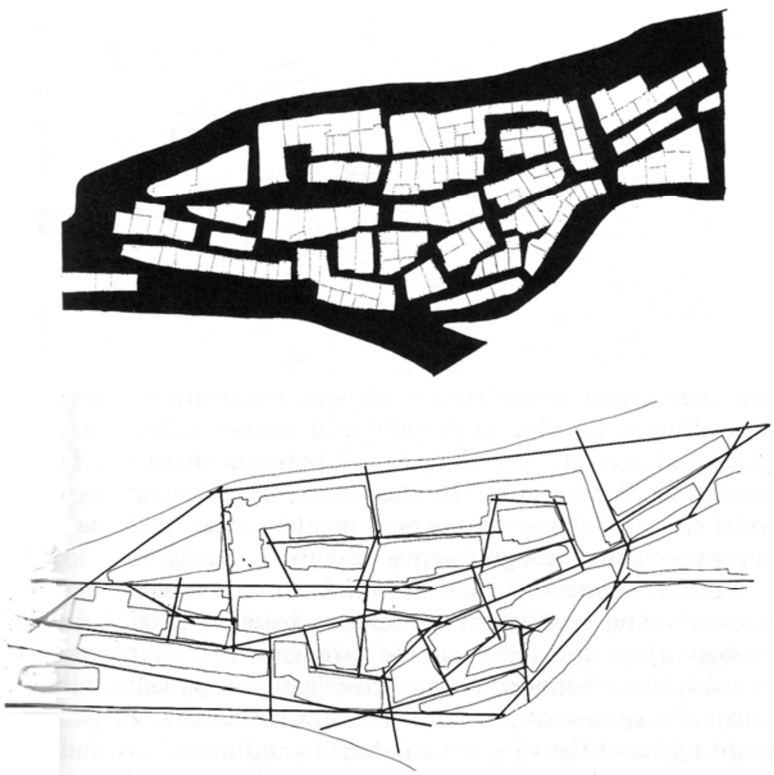


Figure 3.1: Linear map representation of open space in a town.

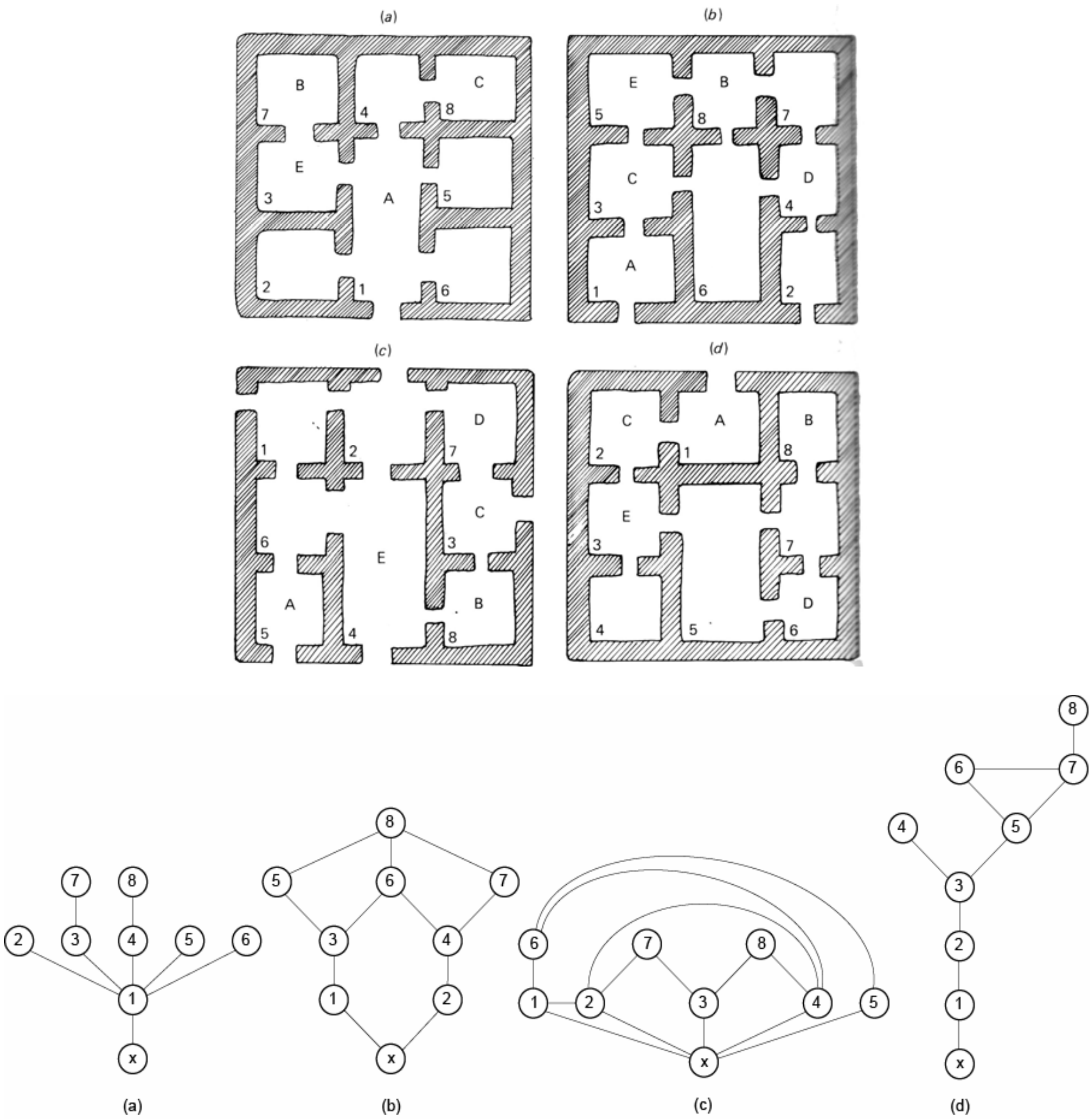


Figure 3.2: Four theoretical buildings and their justified permeability maps (graphs).

A complex C is represented as a graph of k points and connecting lines.

1 The *depth* between two points *a, b* of a complex C is noted as *D(a,b)* and is equal to the minimum number of connections that must be used to reach from *a* to *b*.

2 The *mean depth* of a point *a* in a complex C is defined by the expression:

$$MD(a,C) = \frac{\sum_{b_i \in C} D(a,b_i)}{k-1}$$

k is the number of points in C

3 The *relative asymmetry* of a point *a* in a complex C is defined by the expression:

$$RA(a,C) = \frac{2[MD(a,C)-1]}{k-2}$$

for all *a,C* $0 \le RA(a,C) \le 1$

4 The *real relative asymmetry* of a point *a* in a complex C is defined by the expression:

$$RRA(a,C) = \frac{RA(a,C)}{RA_D(k)}$$

k is the number of points

$$RA_D(k) = \frac{6.644k * \log_{10}(k+2) - 5.17k + 2}{k^2 - 3k + 2}$$

$RA_D(k)$ gives an approximation to the empirically found average RA(a,C) for complexes of size k. Values of RRA vary about 1 so that values above 1 indicate deeper than average complexes and values below 1 indicate shallower than average complexes.

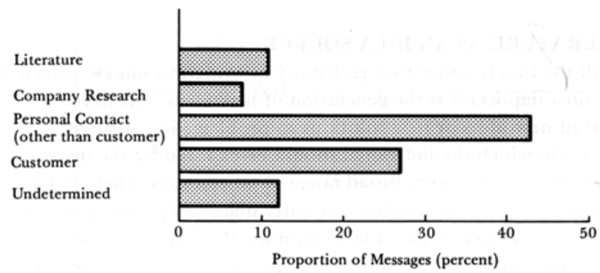
5 The *mean depth*, *relative asymmetry* and *real relative asymmetry* of a complex C taken as a whole is given by the averages:

$$MD(C) = \frac{\sum_{a \in C} D(a,C)}{k}$$

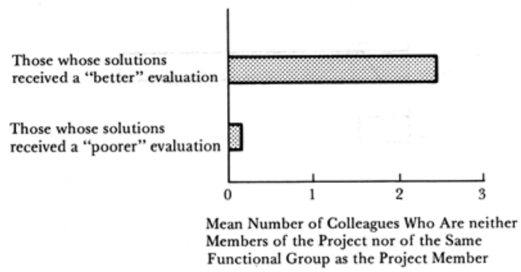
$$RA(C) = \frac{\sum_{a \in C} RA(a,C)}{k}$$

$$RRA(C) = \frac{\sum_{a \in C} RRA(a,C)}{k}$$

Figure 3.3: Definitions of spatial variables of Mean Depth, Relative Asymmetry and Real Relative Asymmetry.



a)



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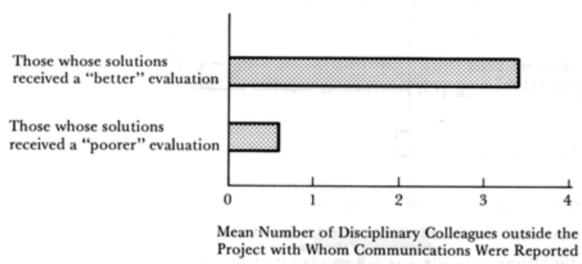


c)

Figure 3.4: a) Prevalence of personal contacts over other means of information for generating ideas considered as potential solutions to technological problems; b) the significance of diversity of contacts outside the project for enhanced performance within disciplinary group; c) outside disciplinary group.

Level One Sub-model: **Strategic Management Variables**

	non-interface core	**interface core**
high density	THAMESC	THAMESN
	YRM2	
	YRMB	
	THAMES4	
	CUP2	
	CUP1	CUPG
	OMNIBUS	
low density	THORNTON	

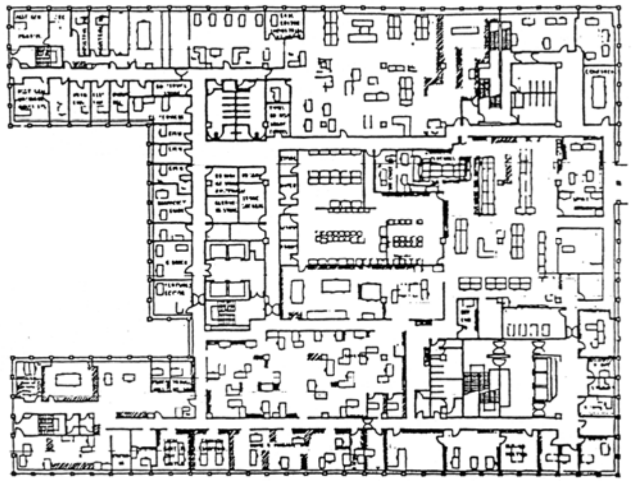
Level Two Sub-model: **Space Metric and Syntactic Variables**

	segregation	**Integration**
k-effect weak	THAMESC	THAMESN
	OMNIBUS	
	YRM2	
	YRMB	
	THORNTON	
	THAMES4	
		CUPG
	CUP1	
k-effect strong	CUP2	

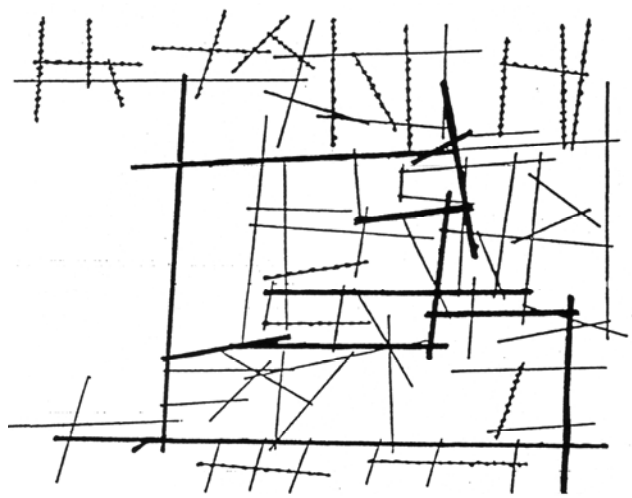
Level Three Sub-model: **Space Use Types**

	high Integration difference for static/moving	**low Integration difference for static/moving**
high communication	YRMB	THAMESN
	YRM2	
	THAMES4	
	CUP2	
	CUP1	CUPG
	THORNTON	(THAMESC)
high work	OMNIBUS	

Figure 3.5: The hypothetical model of characterizing organizations, their space use and layouts by means of relating features of three sub-models in pairs.



a)



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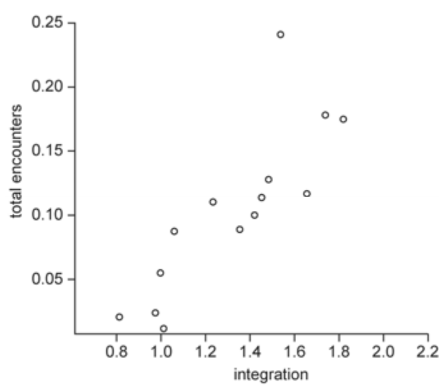
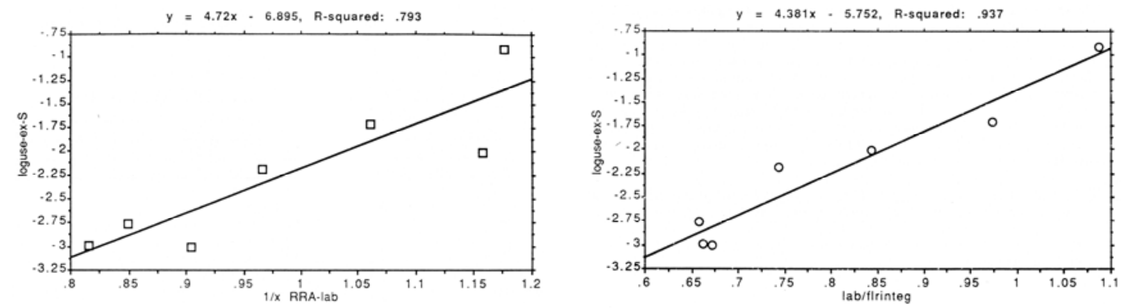


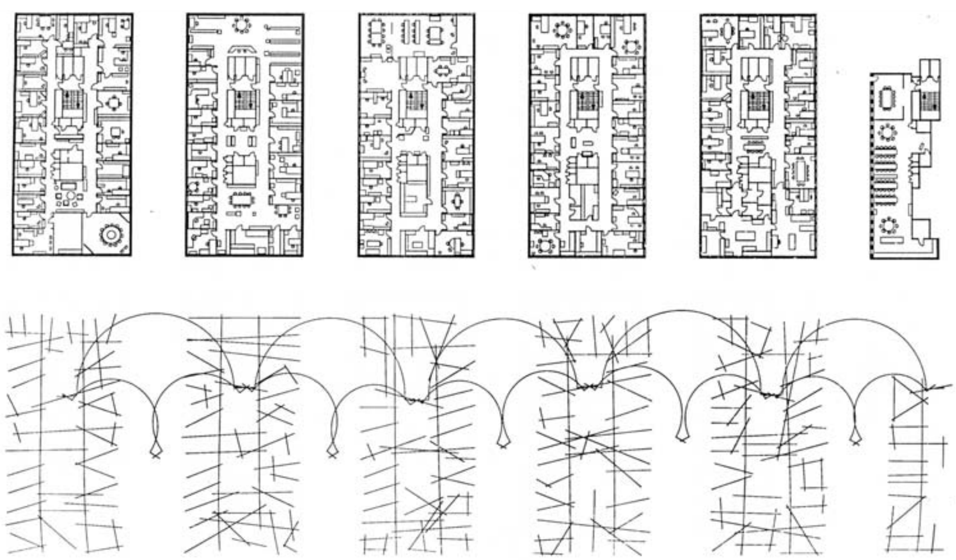
c)

Figure 3.6: Spatial analysis and observed density of space use in the editorial floor of a London newspaper: a) layout; b) the axial integration map of the open plan structure, where the 10 percent most integrated are shown in heavy black; c) scatterplot of the fit between Integration of space and the Observed Density of Space Use averaged over twenty observations at different times of the day.

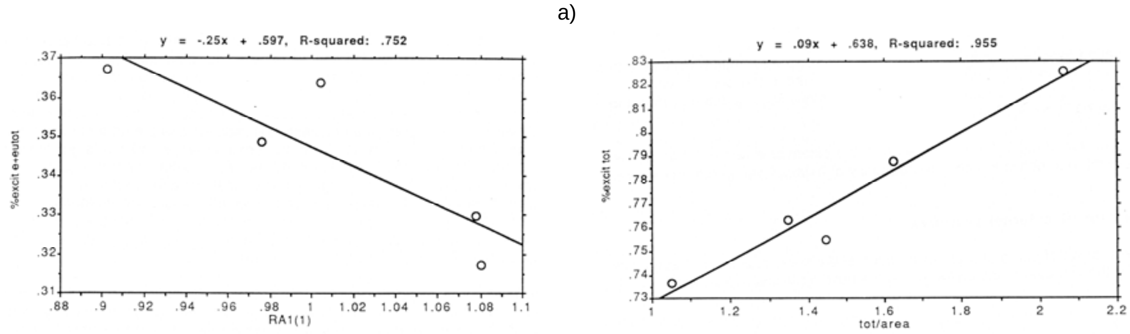


a) b)

Figure 3.7: a) scatterplot between lab (global) Integration and useful contacts for the sample of 7 buildings in the UK; b) scatterplot between Integration Interface (labint/floorint) and Useful Contact Rates.

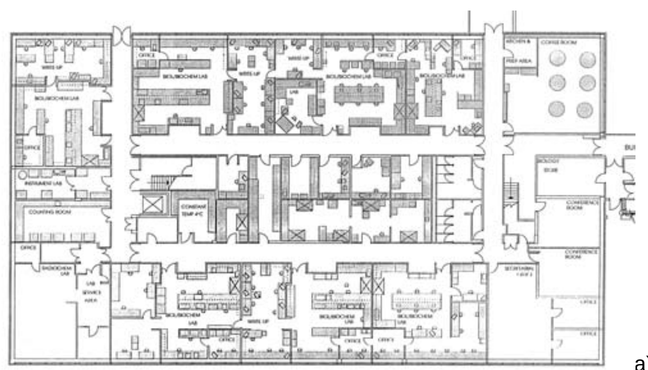


a)

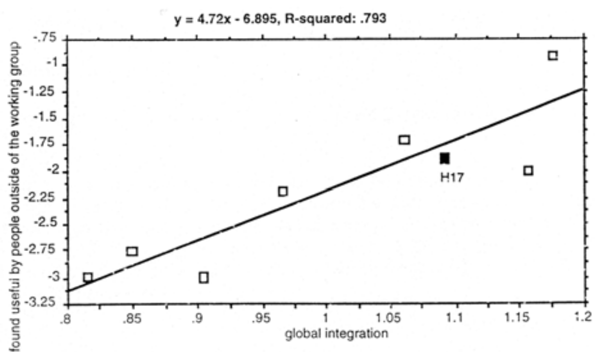


b) c)

Figure 3.8: a) Line map representation for the entire six floors of BFR, Stockholm; b) scatterplot between Integration and Percentage of Citations happening elsewhere from the workplace; c) scatterplot between Density of Occupation (tot/area) and Percentage of Total Citations (workplace + elsewhere).



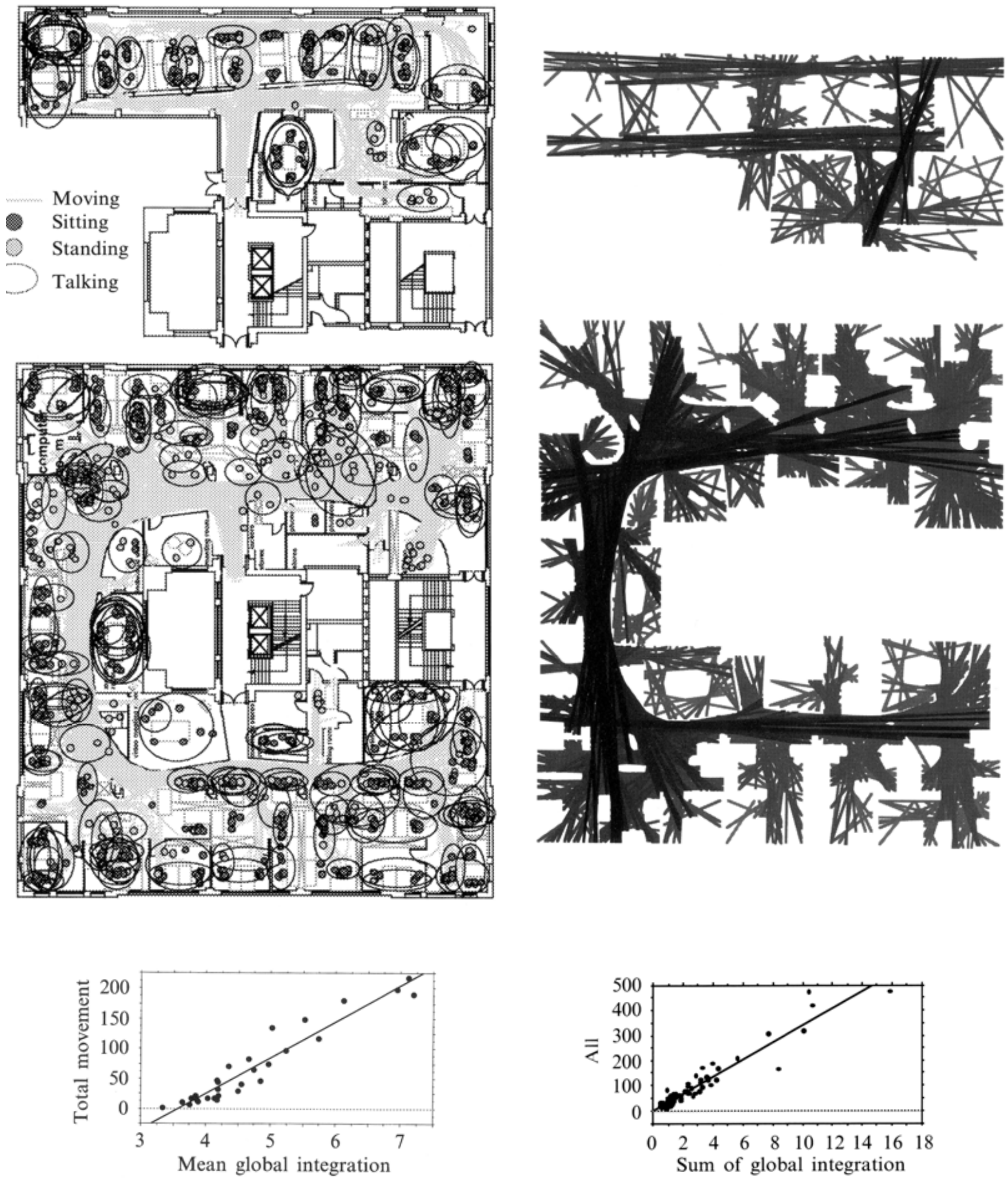
a)



b)

Figure 3.9: a) Layout of Smithkline Beecham H17 refit; b) scatterplot between Integration and Useful Contact Rates for embedding H17 into the existing database of lab buildings in the UK.

a) b) c) d)



r=0.959, p=0.0001

r=0.966, p=0.0001

Figure 3.10: a) Observed patterns of space use and movement in company Y; b) global Integration in the all-line map for the two floors of company Y; c) scatterplot of Movement Observed and Mean Integration value of lines passing through the gate, excluding gates to dead-end spaces; d) scatterplot of all available people and sum of line Integration.

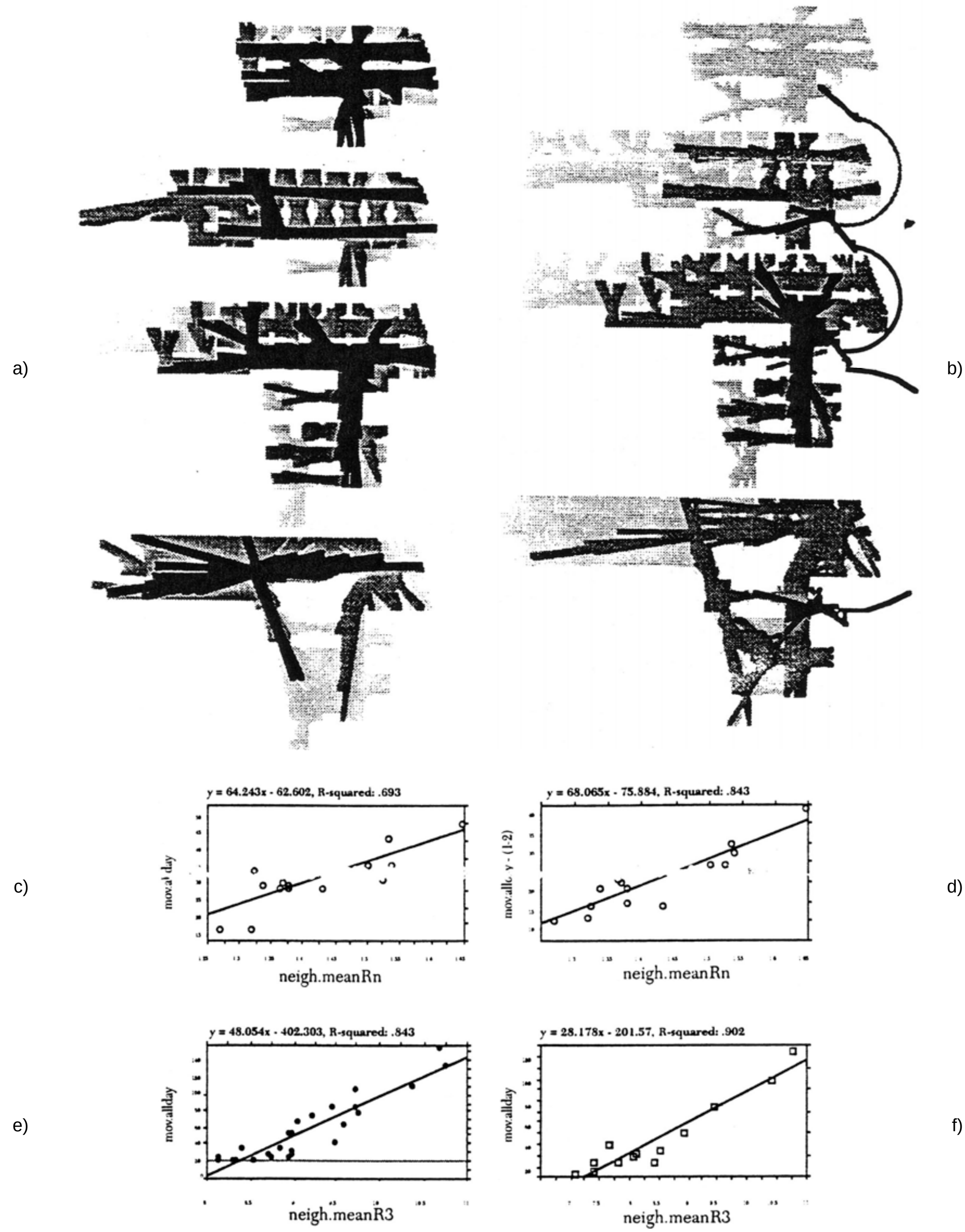


Figure 3.11: Wolf Olins Corp. study.a) all-line analysis for individual floors (dark shows more integrated lines); b) all-line analysis for connected floors; c) movement against global integration excluding restaurant and elevators; d) movement against global integration omitting lunch time observations; e) movement against local integration for the north part; f) movement against local integration for the south part.

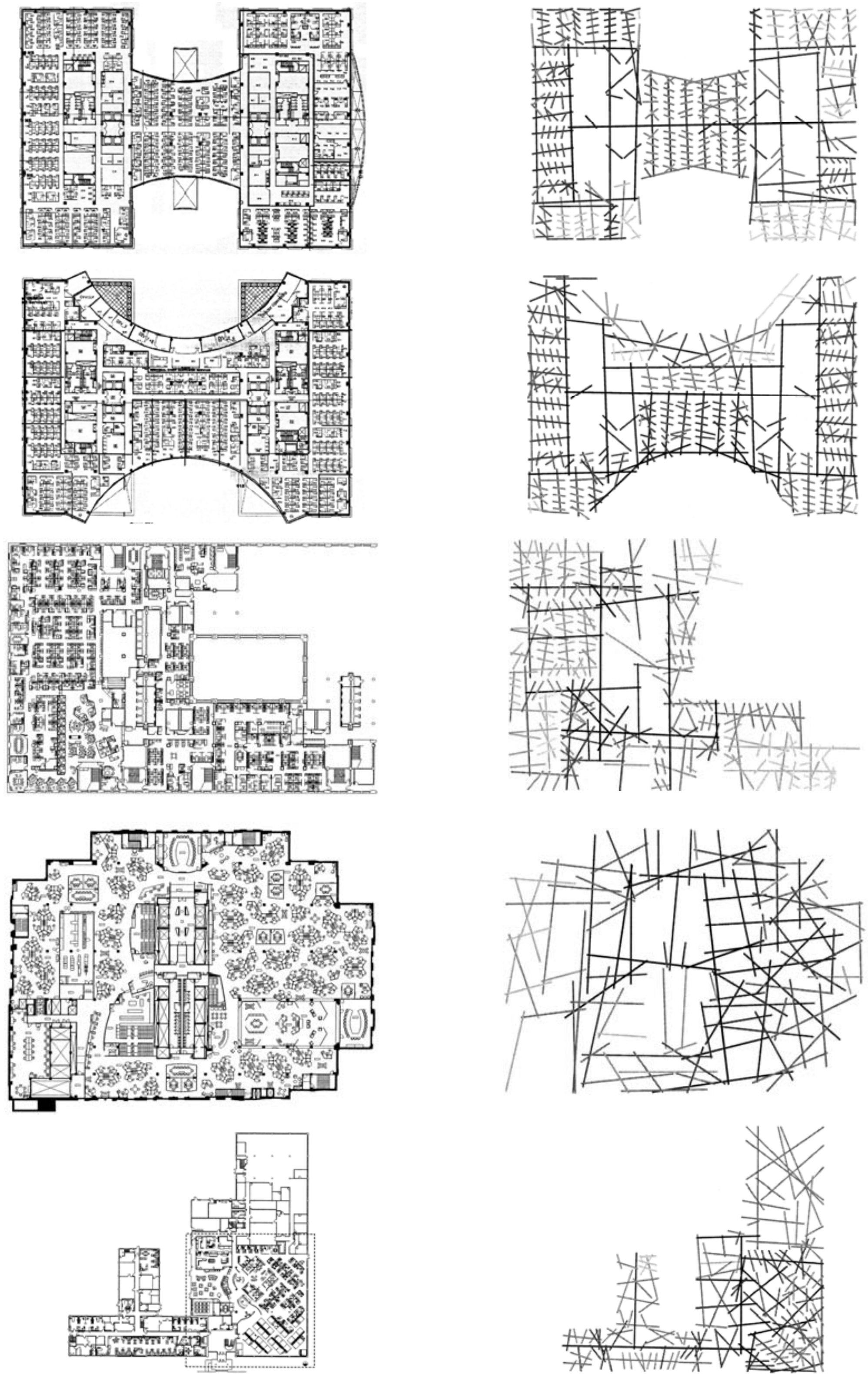


Figure 3.12: Five office layouts and the analysis with linear maps.

case study	shape of circulation core	group territoriality	spatial hierarchy based on accessibility	rank orders of local and global accessibility	orders in geometry and axial structure
1	tree	strengthened by axial structure	reflects functionally distinct spatial categories	do not map onto each other	co-exist
2	tree	strengthened by axial structure	reflects functionally distinct spatial categories	do not map onto each other	partly co-exist
3	wheel	strengthened by axial structure	reflects functionally distinct spatial categories	map onto each other	partly co-exist
4	wheel	not related to axial structure	partly reflects functionally distinct categories	partly map onto each other	order in axial structure exist without geometric order
5	net	weakened by axial structure	reflects functionally distinct spatial categories	map onto each other	partly co-exist

Figure 3.13: Characteristics of five layouts as interface among five spatial descriptions.

Chapter Four

Studies on Representations, Descriptions and Measures of Shape

“It is better to confess that you cannot define exactly ungeometrical figures.”
(Strabo, book V: 314)

Outline

This chapter reviews studies on representing, measuring and describing shapes and discusses the conceptual basis underlying various methods. Shape and the enclosed space form an inseparable duo, where one influences the other depending on our intuition. For the purpose of this thesis, I analyze the shape of floorplates based on the characteristics of the enclosed space. Due to the limited descriptions offered by studies that directly link the geometry of floorplates with the performance of office layouts, the review extends to methods used in geography and geomorphology which address general and abstract features of shapes. Through a critical approach it aims at identifying concepts that may benefit the analysis of shapes from the viewpoint of fitting layouts. Recent research in space syntax addresses characteristics of space by analyzing modular grid representations that have the potential to grasp the metrics of shape, however, the focus is given to assessing the differentiation between regions rather than suggesting robust overall description of shape. The review identifies the need for total and robust configurational measures of shape that take in account metrics in order to pinpoint characteristics of space responsible for affecting the characteristics of layouts.

4.1 Descriptions and measurements of shape with discrete elements

This section reviews existing measures and techniques for describing shapes that are based on discrete elements of shape. Discrete elements of shape include distances between key points in a shape such as vertices, centers of gravity, quadrant points and midpoints; degrees of angles between segments connecting these points; and areas of regions of the shape or the entire shape. Examples of metric lengths between key points are edge segments, diagonals, diameters and the perimeter. According to these descriptions, lengths and areas of distinct elements are used to formulate indices that characterize shapes in a quantitative manner. One of the most popular descriptions of shape belonging to this category is the *compactness* of a shape measured by the Ratio between Area and Perimeter Length. This index has been employed widely by architects as a simple empirical measure of describing shapes of plans for evaluating the environmental conditions in buildings and building cost. March and Steadman (1971) argue that the Area-to-Perimeter Ratio relates “somehow to convenience in circulation, lengths of service runs, amount of external walling and a number of other factors affecting cost.” Our deduction about elongated shapes being associated usually with longer perimeters seems to validate the concept of compactness with the value of this ratio. However, it can be easily proven false by showing that a perimeter jagged in a small scale of local indentations, hence a greater value of this ratio, may coincide with a compact shape.

In another study, Markus et al. (1970) devise the Plan Compactness as the ratio of perimeter of a circle of area equal to the total floor space to the actual perimeter of the building (**figure 4.1a**). Also using the shape of the circle as a yardstick, the Index by Miller (1953) is calculated by the ratio of the area of shape under consideration to the area of the circle having the same perimeter (**figure 4.1b**). Whereas, the Coefficient of Compactness by Cole (1964) is expressed as the ratio of the area of the shape under consideration to the area of the smallest circle that encloses the shape (**figure 4.1c**).

Most of the shape descriptions used by geographers, reviewed by Haggett and Chorley (1969), consist of relations between discrete elements of areas, perimeter, axes, and radial axes from centroid to perimeter, which are similar to the radials used for describing isovists (Benedikt 1979). The relationship between *area* and the *length of the longest axis* in the shape constitutes the foundation for four geographical methods of Form Ratio (Horton 1932), Elongation Ratio (Schumm 1956), Ellipticity Ratio (Stoddart 1965) and Shape Index (Haggett 1965) (**figure 4.1d to 4.1g**). Critiquing these methods, Blair and Biss (1967) emphasize that measures which are based on the area and the length of boundary enclosing the shape are too crude and not sensitive enough to capture features resulting from the shape indentations. The shape descriptions which use the length of radials include: the Radial-Line-Ratio by Boyce and Clark (1964); the Variance of Radials and the Skewness of Radials by Benedikt (1979).

The measurement of shape by Bunge (1962), while being based on discrete elements, offers *unique* descriptions of shape, i.e. no shapes that differ from each other can have equal descriptions. This method uses distances between selected vertices of an equilateral polygon that approximates the shape under consideration (**figure 4.2**). It is founded on two theorems stating: that any shape can be approximately matched by a closed polygon of any number of sides whose sides are of equal but variable length; and that any polygon enjoys a one-to-one correspondence with the unique sums of distances between all vertices lag-one, lag-two, lag-three and sums of squares of these distances. A shape thus is represented by a list of six numbers that is unique to the shape. While being unique, differences between shapes, drawn by comparing their six numbered lists do not relate to any feature of shape which we could intuit.

It should be noted that Duffy's classifications of floorplates according to the *space stock capacity* and the metric *depth* between core and perimeter (Duffy, Cave & Worthington 1976), discussed earlier, have a discrete character, as well. In contrast to methods used in geography, which are based on abstract concepts, these descriptions are based on clear intuitive notions about perception of space.

4.2 Descriptions and measurements of shape with continuous infinitesimal representations

Descriptions of shape that are based on infinitesimal representations take into account specific relations among modules of shapes which are constructed either by dividing the shape into small modules according to a regular grid, for example orthogonal grid, or are randomly located inside the shape, such as the case of a large number of random points.

An example of descriptions of shape based on modular representations is the calculation of Compactness of shape proposed by Blair and Biss (1967). According to this method, shapes are split up into an infinite number of infinitesimal elements of area. Similar to the method by Boyce and Clark (1964), the center of gravity of the shape (or the center of gravity of the complex in the case of shapes composed of many islands) is chosen as the epicenter for distances of units of the shape. However, in contrast to aggregating distances from center of gravity to perimeter of equally spaced radials (Boyce and Clark 1964) (**figure 4.1h**), distances to all shape units are aggregated using infinitesimal calculus (**figure 4.3**). It is argued that this method allows measuring the compactness of two-dimensional shapes overcoming problems of other methods with regard to the high degree of *fragmentation*, *dispersion* into islands, gross *distortions* and *punctured* shapes. The circle, as the most compact shape, has a Compactness of 1, whereas the index has lower values for less compact shapes. **Figure 4.4** shows the comparison of the Compactness by Blair and Biss' with the Index proposed by Haggett (1965) and Cole (1964) for some basic shapes.

4.3 Modular grid representations of shape

Modular representations are based on mapping and approximating the shape with square modules according to superimposed orthogonal grids with fixed modular dimensions. The size of the module would affect the dimensional approximation of the representation so that finer grids would achieve a better mapping, while more computation time. Placing together square units of equal size produces the interesting geometrical class of polyominoes (Golomb 1996). Most problems, games and puzzles with polyominoes involve listing the possible patterns of packing together a number of cells into polyomino shapes, patterns of packing different polyominoes to fill larger shapes, as well as ways of coloring the arrangements. Apart from these problems that belong to the field of combinatorial geometry, a few studies with polyominoes have aimed at representing architectural plans and measuring some of their properties (Frew 1973, Mitchell and Dillon 1972, Matela 1974). Of particular interest to this discussion are the four indices of describing shape proposed by March and Matela (1974) (**figure 4.5**). In spite of the claim that these indices describe properties of shapes, they describe only features of specific polyominoes but not the features of their contouring shapes. **Figure 4.6** shows the calculation of the four indices for a shape represented with 6 cells and 24 cells. It is evident that only Density and Proportion are not affected by the size of the modular unit used for the representation, whereas two measures of Shape Index and Perimeter Index get different values for two representations and thus cannot be used to capture characteristics of the shape as claimed. When representing shapes with polyominoes, or arrangements of square cells, taking away the effect of size remains an unsolved issue for some of these methods. Only measures that do not depend on the number of representation cells can be used to gauge features of shape.

Matela and O'Hare (1976a) have studied the geometry of networks represented by polyomino cells to understand the effect of shape in the statistical distribution of distances over a population of polyomino families. This model considers metric distance as an important aspect of approaches for allocating functions and organizing architectural plans. Three kinds of distances between centers of pairs of cells in polyominoes are proposed: first, the *taxicab* or rectangular distance that is measured by adding the differences between *x* and *y* coordinates in a system parallel to the sides of the polyomino (**figure 4.7**); second the *Euclidian*, or else the straight-line distance between two centers of cells; third, the *graph metric distance,* which is the shortest distance between two centers of cells along an orthogonal path that passes inside the shape. Each of the distances: taxicab, Euclid or graph metric, are aggregated in three levels: first, *intercellular* between any two cells (cell-to-cell); second, *aggregate* distances between any cell and all others (cell-to-all-cells) that reveals relative proximities of cells in comparison to others in the shape; third *total* distance which is a sum of the aggregate distances of all cells (all-cells-to-all-cells) that shows the compactness or elongation of the shape of the polyomino. The graph metric distance is calculated by using the adjacency matrix of the polyomino devised by Matela and O'Hare (1976b). The study has two main findings: first, it shows that the differentiation between Euclidian distances in one hand, and taxicab and graph metric on the other, reinforces the use of the latter for constructing models of approximating circulation routes in buildings; second, it supports the idea of choosing shapes of floorplates that are statistically typical and favor loose fit of organizations into buildings due to producing statistically typical distribution of distances that connect activities. Leaving aside the argument on the usefulness of formulating procedures that automate designs in order to regulate distances between activities, Matela and O'Hare's study is relevant to this thesis due to suggesting ways of describing features of shapes by means of aggregating distances between internal locations.

4.4 Configurational measures based on modular representations

As it was discussed in the previous chapter, the term configurational defines qualities that are based on the relations of parts to each other considering all other parts of the system. (Hillier and Hanson, 1984; Hillier, 1996; Peponis, Wineman et al. 1997). With regard to the configurational description of shape, there are two principal terms: first, parts or components or elements of the shape, second, the nature of relations between elements. There is a fundamental difference between geometrical measures that consider the shape in its entirety for deriving descriptions of shape and configurational measures that considers the entirety of the relations between units of shape with regard to all other units. For instance, while the compactness of shape, defined as the area-to-perimeter ratio, considers the entire area and the perimeter, it does not address relations between parts of the shape.

Only a few measures proposed by space syntax research are aimed towards properties of shape per se, or can be modified and used to assess features of shape. The majority of studies in space syntax have aimed, on the contrary, towards analysis of space, often with a clear bias towards neglecting metrics. The descriptions of architectural plans with s-partitions and e-partitions (Peponis, Wineman et al. 1997) emphasize the importance of shape for determining the definition of convex elements for the partitioning. The shape of the building plan, according to this study, is defined as a set of wall surfaces and a set of discontinuities of edges and intersection of walls. The partitioning of the plan into discrete elementary space units is based on the transitions of appearance and disappearance of surfaces and edges from the field of view of a moving observer (**figure 4.8**). The shape is given priority in the inseparable *duo* of shape and spatial structure since spatial structuring is considered an effect of shape. Putting shape ahead of space avoids the ambiguities of convex partitioning with fewest and fattest spaces.

Psarra and Grajewski (2001) build upon the descriptions of Peponis, Wineman et al. (1997) by describing the configuration of *space* by analyzing the visibility between units of *tessellated perimeters* of shapes that encloses it. This model offers robust measures that take the entire shape into account by measuring the local characteristics of perimeter from the viewpoint of the synchronous visual information of the open plan provided to an observer moving along it. Three shape indices are proposed: First, the MCV is the mean of the connectivity values of each perimeter unit and accounts for the level of occlusion or break up of a shape. Second, the index of V-Value measures the standard deviation of connectivity values along the perimeter length and expresses the *differentiation* and the balance between the parts and the whole. High values represent a configuration in which a dominant shape is balanced against subsidiary shapes attached to it. Third, the H-Value measures the frequency of changes in the values of connectivity for perimeter locations. It expresses the *stability* of the shape and stands for the level of repetition or rhythm along the perimeter. Psarra and Grajewski's perimeter method shares one of the aims of this thesis of proposing robust measures that aspire to capture key configurational characteristics of the space in architectural plans. The concept of visibility, on which the method is based, is a key characteristic that affects the intelligibility of space, and consequently the intelligibility of fitted layouts. In spite of this promising aspect, the three indices of MCV, H-Value and V-Value (similarly to s-partitions and s-partitions) are unchanged with respect to any *affinity* transformation of the shape, i.e. transformations that preserve *parallelism*, *cross-ratio* and *neighborliness*, (**figure 4.9**). Floorplate descriptions need to utilize representations that are sensitive to shape transformations whereby shape and dimensional properties are inseparable. By definition, this requirement renders unfit for the purpose of this thesis all shape descriptions that are based on dimensionless representations (Newman 1938, Steadman 1983).

Recent applications in space syntax have utilized representations of plans as dense systems of small tessellated units. The method of *visibility graph analysis* has been used to describe spatial complexes based on the feature of co-visibility between two locations in the spatial complex (Braaksma and Cook, 1980), (Turner and Penn, 1999; Turner, Doxa et al. 2001; Turner, 2001;

Conroy-Dalton and Dalton, 2001). Locations are defined as points from an overlapping grid that fall inside the space or shape in consideration. The approach is a derivation of isovist analysis (Benedikt, 1979; Benedikt and Burnham, 1985) where the degree of visibility of all locations in the lattice is assessed instead of considering single isovists. The method constructs a graph where vertices represent the grid locations in the space and edges represent the visibility relations between locations. Such a graph is defined uniquely for any shape depending on the dimension of the modular grid. In contrast to the local measures of Neighborhood Size and Clustering Coefficient, the third measure of Turner, Doxa et al. of Mean Shortest Path Length is global and can be used for describing shapes in their entirety. The Mean Shortest Path Length is the average of shortest path lengths from a location to all other locations and thus represents the average number of turns required to reach all locations in the space (**figure 4.10**). The pattern of distribution of values of mean shortest path length describes shapes according to the global configurational property of number of turns needed while traveling from any location to all others. Despite being based on the same concept of co-visibility between modular points, this method is radically different from Psarra and Grajewski's due to the fact that grid points fill the entire space rather than just the perimeter, consequently grasping metrics of the shape. However, this method, similar to the one by Peponis, Wineman et al. (1997), follows a 'shape down towards space' approach since it is shape, i.e. the contour of building perimeter and internal holes, that cuts out and defines grid locations. The distribution of internal locations in a modular grid analysis becomes the representation of shape. Turner, Doxa et al., however, miss the opportunity of suggesting robust descriptions of the entire shape by visibility graph analysis and discuss instead how parts of spatial complexes perform with respect to others. The method goes as far as the depiction of differentiation and comparison between parts in a complex without compiling any overall shape description. For instance, the main central space in a museum gallery is shown to have low values of the measure in comparison to other peripheral spaces in the complex, but, if not for the comparison between internal spaces, no discourse is possible between the museum in consideration and other buildings.

In the chapter “Non-Discursive Technique”, Hillier (1996) analyzes shapes as configurations of relations among their constituent units, which are based on grid representations. By analyzing the justified graph based on units of the shape, it is demonstrated that symmetries of the shape can be gauged by counting the isomorphism of the j-graphs of shape units. Hillier proposes the measure of Symmetry Index of a shape as the ratio between units that share the same total depth value to the overall number of units in the shape (**figure 4.11**). The calculation of this index for two cases when the same shape is represented with two different grains of 6 and 24 units shows that the index varies depending from the size of the representation unit (**figure 4.12**). Therefore, it cannot measure a specific feature of shape.

In an effort to incorporate metric qualities of environments of length and area into conventional axial and convex analysis Hillier, Penn, Dalton, Chapman and Redfern (1995) have proposed the technique of *layered tessellation* that considers the calculation of Depth, and consequently of Integration, based on the linkage of two superimposed layers: the first representing the linear system of circulation spaces of streets in urban environments or corridors in buildings where each linear element is considered one graph vertex; and the second representing all the linear and convex spaces in the complex with tessellated units and considering each one as a graph element. The combined graph regards the connectivity between linear elements and the adjacency connections between modular units of shape. The two layers are plugged into each other to create links between modular units and linear units that have a projective relationship. The Length Weighted Integration, as it has been termed, has been argued to capture more realistically features of the environment and, apart from length, to be potentially used for loading the street system with number of floors of adjacent buildings, sewage, electrical networks or underground systems.

4.5 Discussion

The review of studies on the description and measurement of shape was underlined by two main themes: First, it addressed the identification of shape descriptions which can be borrowed and used in their existing form for the purpose of describing floorplate shapes from the viewpoint of fitted office layouts. Second, it sought to discover methods, concepts and criteria of evaluation, which allow modifications and applications to aid new descriptions of floorplate shapes. The benchmark for testing the applicability of shape descriptors consisted on whether a link can be drawn between the elements supporting the shape description and characteristics of built environments close to our intuitive understanding of spatial qualities.

Faced with the difficulties of describing and measuring shapes, scientists in geography, computational geometry and computational morphology take various positions that range from describing shape empirically to proposing methods of dissecting complex shapes into simpler parts guided by meaningful procedures rather than just simple geometrical components. Toussaint (1988) considers the study of form an object of *morphology* rather than *geometry*, since "*shape* or *form* of an object is not a well-formalized concept" and notes that "any mathematical description of shape and form thus far conceived, no matter how sophisticated, has always fallen short of what was hoped for."

Studies in geography and geomorphology have sought descriptions of shapes as abstractions and representations of large land masses and regions. Due to the scale involved in descriptions of shape in geography and geomorphology, there is no direct relation between shape descriptors in geography and the human perception of environments enclosed inside these shapes.

In contrast, shape in architectural research stands out as representation of environments of a perceptible scale, whereby there exist a tight relationship between elements of shapes under consideration and our perception of the environment. For example, the depth from core to perimeter used by Duffy (1976) while being based on discrete elements of lengths relates directly to both human perception in building floors as well as to an important factor for architectural design of office environments with direct implications to types of layouts to be accommodated. Nonetheless, this discrete element is local to particular parts of the floorplate shape and, as is it was discussed in Chapter Two, cannot be used to successfully describe the entire floorplate.

The review identified two classes of methods for describing shapes: those based on discrete elements and those based on infinitesimal representations. The first class is founded on characteristics of area and length of discrete elements such as diagonals, diameter, axis, sides, radii and perimeter. Most of these methods that calculate shape indices by combining area and perimeter cannot adequately describe shapes with holes or punctuations, shapes with complex jagged contours, and shapes that are extremely distorted. However, the main issue from the viewpoint of this thesis is that even descriptions that have withstood the mathematical testing (Bunge 1966) are founded on discrete elements that lack the significance with regard to human perception of space and shape. Descriptions of shape based on discrete elements cannot suffice to provide global descriptions that relate to human perception of space since discrete elements characterize either local characteristics of shapes or they characterize global characteristics without a direct link to the human intuition about spatial conditions

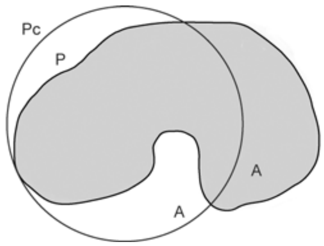
The second class of methods for describing shape identified by this review is founded on infinitesimal representations of shape with small units. Specific characteristics of shape units are considered to sum up an index for the shape where each and every unit contributes in the aggregate measure. Studies with the geometrical class of polyominoes showed that modular representations are associated with the issue of removing the effect of the module size from descriptive indices.

Recent studies in space syntax have utilized modular representations for analyzing built environments where relations among units are associated with fundamental spatial conditions of visibility and permeability between locations. These studies describe spatial complexes based on comparisons between integrated and segregated regions, while no overall robust descriptions for the entire complex have been given. By exception, Psarra and Grajewski's method is addressed at formulating overall descriptions based on the visibility between units of perimeter. Despite this advantage, the method is insufficient for providing unique descriptions since it does not consider metrics of shape.

With regard to the quest for finding descriptions of floorplate shapes, the infinitesimal and modular methods have a threefold advantage: First, these methods lend themselves to associations with continuous qualities of space. In contrast to fragmented environments of buildings partitioned into rooms, large open building floors contain spatial conditions of a continuous nature. Second, modular representations allow gauging these qualities in a configurational way by considering relations between shape units regarding all other units. As it is discussed in the next chapter, configurational descriptions of layouts have demonstrated strong and significant links with aspects of performance in office organizations. The discussion on Duffy's model (1976) in the previous chapter identified the need for compatible descriptions between floorplates and layouts that belong to the same domain of analysis. Hence, it is suggested that configurational descriptions of floorplate shapes have the advantage for providing both compatible descriptions with space syntax descriptions of layouts as well as a natural tendency to depict significant relations between two sides of configurational indices. Third, modular methods take into account dimensional aspects of shape by weighing the configurational analysis with metrics of size and distance. Metrics are essential for influencing fitted layouts, for instance, the depth from core to perimeter, as shown by Duffy determines what kind of layout can occupy a part of floorplate. The very requirement of an organization to accommodate a certain number of workspaces translates into square footage and distances, thus metrics. Layouts are organized first of all by putting together sizeable elements of workspaces with specific dimensions according to ergonomics and nature of the work process.

Modular grid representations in association with configurational descriptions allow analyzing features of shape in a unique way. The advantage of the modular grid representations consist of the *weighting* of the configurational analysis with metrics, i.e. the effect of size, area and distance. In conclusion, this review suggest the need for formulating new configurational descriptions of floorplate shapes according to principal spatial conditions of elemental units of space constructed via modular representations.

a)



Plan Compactness $\frac{P}{P_c}$

P perimeter
A area
equal area

Markus et al. (1970)

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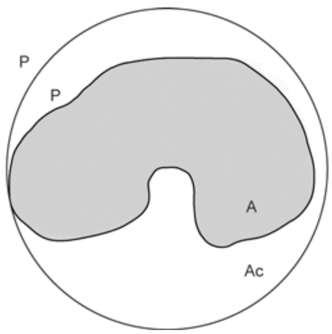
b)



Circularity Ratio $A / \left\{ \pi \left(\frac{P}{2\pi} \right)^2 \right\}$

A area (square km)
P perimeter (km)
equal perimeter

Miller (1953)

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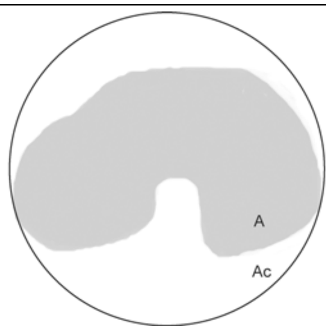
c)



Coefficient of Compactness $= \frac{A}{A_c}$

A area (square km)
A_c area of circle (square km)

Cole (1964)

A area (square km)
L major axis (km)

d) **Form Ratio** A / L^2 — Horton (1932)

e) **Elongation Ratio** $\left\{ 2\sqrt{\frac{A}{\pi}} \right\} / L$ — Schumm (1956)

f) **Ellipticity Ratio** $L / 2\left\{ A / \left[\pi \left(\frac{L}{2} \right) \right] \right\}$ — Stoddart (1965)

g) **Shape Index** $S = (1.27A) / l^2$ — Haggett (1965)

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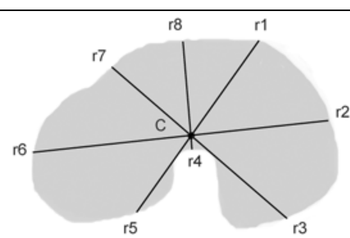
h)

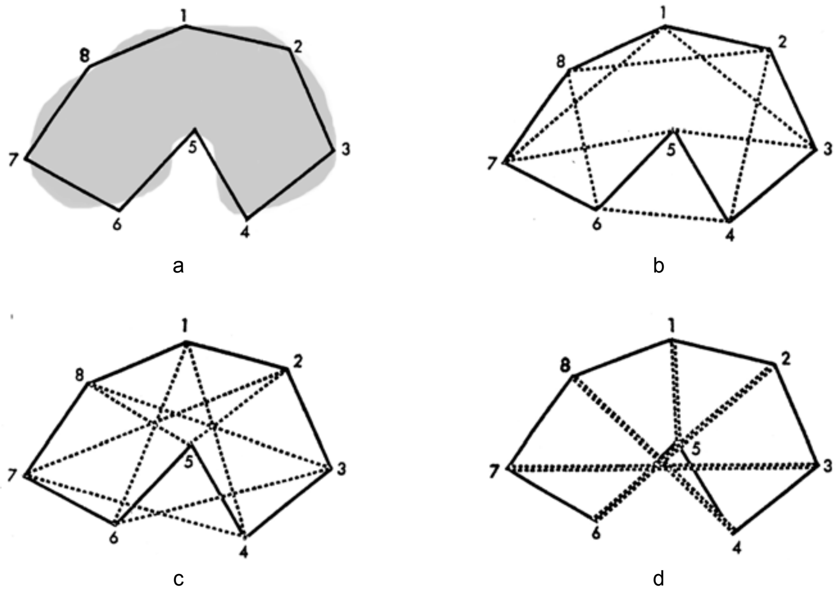


Radial-Line Ratio $\sum_{i=1}^{n} \left\{ \frac{100\frac{R_i}{n} - \frac{100}{n}}{\sum_{i-1}^{n} R_i} \right\}$

Ri radial axes from gravity center to perimeter (km)

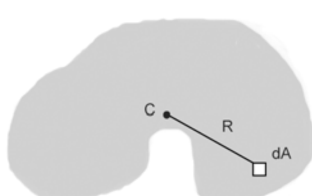
Boyce & Clark (1964)

Figure 4.1: Alternative measures for the comparison of the shape of closed figures based on discrete elements.



shape (side = 1 unit)	S1	S2	S3	$S1^2$	$S2^2$	$S3^2$
	12.1	18.3	16.4	24.0	24.0	24.0
	11.8	18.0	15.9	24.0	24.0	24.0
	10.9	17.3	15.7	24.0	24.0	24.0
	10.2	16.6	15.2	24.0	24.0	24.0

Figure 4.2: Bunge's method for expressing the shape index as a list of 6 numbers by aggregating 3 "lag" distances and their squares. Top: a) approximation of shape with an equilateral polygon, b) drawing distances between vertices (lag-one), c) drawing distances between vertices (lag-two), d) drawing distances between vertices (lag-three). Above, shape calculation for 4 basic shapes.



Compactness Index

$$\frac{A}{\sqrt{2\pi\int_a R^2 dxdy}}$$

Blair and Biss (1967)

R radius from unit to gravity

Figure 4.3: The Compactness Index proposed by Blair and Biss. C - centroid or the gravity center of the shape; r – radius; dA – elementary unit of shape.

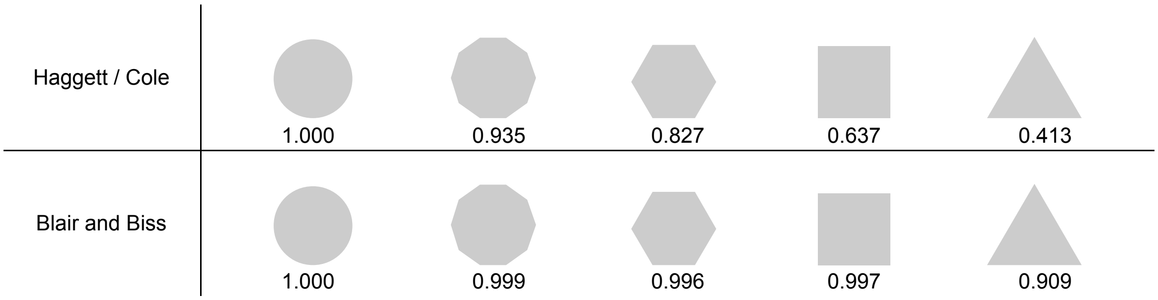


Figure 4.4: A comparison of compactness indices of regular shapes measured by two techniques by Haggett / Cole and Blair and Biss.

1 The **Shape Index** α of the *N*-omino is the ratio of the number of walls to the number of partitions

$$\alpha = \frac{\# ext\Pi_1}{\# int\,\Pi_1}$$

ext, or *wall*, is the edge belonging of the perimeter of the shape
int, or *partition*, is the edge inside the shape
When *α* is high the *N*-omino is strung out, when *α* is low it well packed.

2 The **Perimeter Index** *γ* of the *N*-omino is proportional to the number of walls with respect to the number of faces

$$\chi = \frac{\# ext\Pi_1}{4N}$$

The *γ* index measures the architectural property of perimeter-to-area ratio, and ranged between 0 and 1.

3 The **Density** *δ* of the *N*-omino with respect to its rectangular cover is given by

$$\delta = \frac{N}{\# B}$$

B is a square cell of the bounding rectangle or grating. The value is smaller or equal to 1 as is the case of a rectangular polyomino that fits completely its cover.

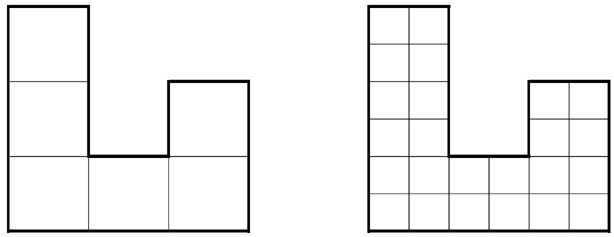
4 The **Proportion** *π* of the *N*-omino is given by

$$\pi = \frac{n2}{n2}$$

n1 and *n2* are the dimensions of the rectangular cover *B*

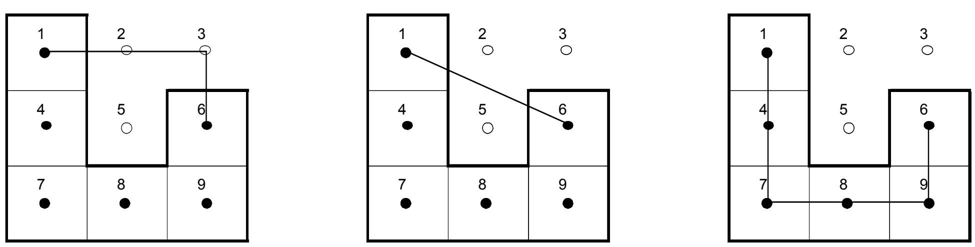
and $n1 \geq n2$. The value of *π* ranges $\frac{1}{N} \leq \pi \leq 1$

Figure 4.5: Indices of polyomino arrangements proposed by March and Matela (1974).



	6-omino representation	24-omino representation	size effect
Shape Index	$\alpha = \frac{14}{5} = 2.8$	$\alpha = \frac{28}{34} = 0.824$	yes
Perimeter Index	$\chi = \frac{14}{4*6} = 0.583$	$\chi = \frac{28}{4*24} = 0.292$	yes
Density	$\delta = \frac{6}{9} = 0.667$	$\delta = \frac{24}{36} = 0.667$	no
Proportion	$\pi = \frac{3}{3} = 1$	$\pi = \frac{6}{6} = 1$	no

Figure 4.6: The effect of size of the module of representation on indices proposed by March and Matela (1974).



taxicab metric	Euclidian metric	graph metric
$d_T^{1,6} = 3$	$d_E^{1,6} = \sqrt{5}$	$d_G^{1,6} = 5$
${}_6^kD_T^* = (13,9,11,8,9,11)$	${}_6^kD_E^* = (9.8,7.7,9.0,8.3,6.5,9.1)$	${}_6^kD_G^* = (15,11,15,9,9,11)$
${}_6^kD_T^{**} = 61$	${}_6^kD_E^{**} = 52.4$	${}_6^kD_G^{**} = 70$

Figure 4.7: Three types of metric distances and three levels of aggregation for a 6-omino. The bold line shows the distances between point 1 and 6. The intercellular, aggregate, and total distances for 6 cells are shown below each diagram.

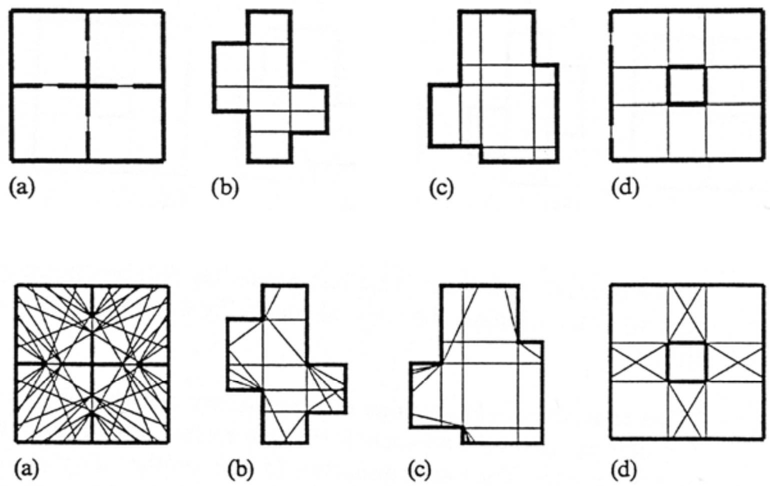
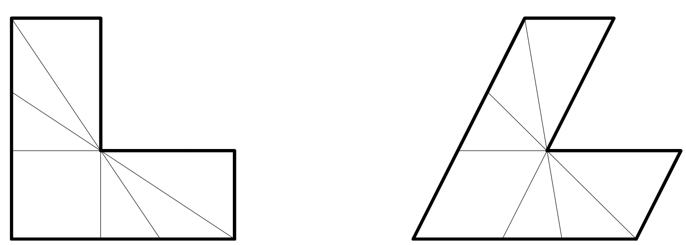


Figure 4.8: Representation with *s-partitions* (top); and *e-partitions* (above) of four hypothetical plans.



MCV=75.7; V-Value=15.3; H-Value=16.1 MCV =75.7; V-Value=15.3; H-Value=16.1

Figure 4.9: Calculating the perimeter visibility proposed by Psarra and Grajewski (2001) for two shapes derived by an affinity transformation. Equal values of three measures and equal s-partition and e-partition describe two different enclosed areas.

The Mean Shortest Path Length $\bar{L}_i$ for a location v_i

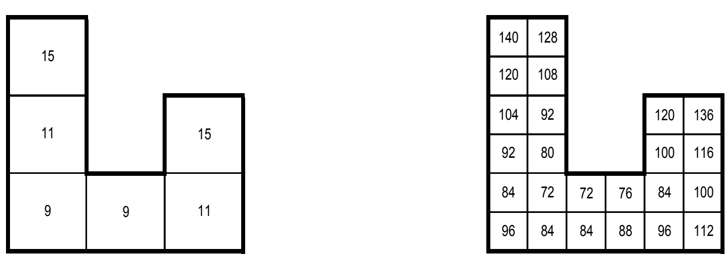
$$\bar{L}_i = \frac{1}{|V|} \sum_{j}^{v_j \in V} d_{ij}$$

A path from v_i to v_j is a sequence of unique intervening vertices between v_i and v_j such that consecutive vertices in the sequence are joined by an edge in the graph. The distance d_{ij} between v_i and v_j is the length of the shortest path between them.

Figure 4.10: Definition of the Mean Shortest Path Length.

$SI = \frac{9}{30} = 0.3$ $SI = \frac{21}{30} = 0.7$ $SI = \frac{26}{30} = 0.867$ $SI = \frac{13}{30} = 0.433$

Figure 4.11: Symmetry Index for four shapes composed of 30 units.



a) $SI = \frac{3}{6} = 0.5$

b) $SI = \frac{16}{24} = 0.667$

Figure 4.12: The effect of size of the module of representation on the Symmetry Index proposed by Hillier (1996): a) shape is represented with 6 units; b) shape is represented with 24 units.

Chapter Five

Robust Configurational Descriptions of Floorplate Shapes

Outline

This chapter addresses the issue of describing shapes of floorplates from the viewpoint of their effect on layouts fitted in them. The understanding of floorplate shapes is considered fundamental for pinpointing characteristics of space that are responsible for influencing the performance of layouts linked to the measure of Integration. The proposed methodology has been founded on two primarily goals: First, configurational descriptions of shape have been sought, where relational correspondences between all units in the shape are aggregated for describing the shape. This contrasts to methods used in geometry and geography, where discrete elements of area, perimeter, diameter, diagonals and angles are used to describe shape. Second, the identification of underlying structures of shapes that guide the relationship between two-dimensional elements of shape and one-dimensional elements of circulation system necessitates a dynamic model, where units of shape can acquire different natures in accordance to their role as occupation or circulation spaces in the building while preserving their relational effect on the complex. Two measures of shape are proposed: Relative Grid Distance, which expresses the compactness of shape; and Convex Fragmentation which gauges the extent to which the shape is divided into different overlapping maximal convex areas. A new typology of floorplates is proposed based on the analysis of fifty office floorplates with the two measures.

5.1 Relative Grid Distance: Measuring Floorplate Shapes with Universal Metric Distances

The distance of travel has a close relationship with our experience of moving inside buildings. A number of studies (Frankl 1914, Cassirer 1955, Piaget and Inhelder 1967, Gibson 1979) have recognized movement as a basic premise for our understanding of buildings. Through movement, an observer is able to experience different facets of buildings as part of understanding its entirety.

From the perspective of a moving observer and the nature of information he retrieves, there exists a notable difference between two kinds of environments: cellular spaces, i.e. densely partitioned buildings consisting of repeated rooms of comparable size, and large open-plan buildings, which are continuous and unobstructed by internal walls (Steadman 1998, Steadman et al. 2000). In the first kind, mostly characterized by partitions, our moving experience is formed by transitions from a space to another as key thresholds of s-partitions and e-partitions (Peponis, Wineman et al. 1997) are crossed. A full understanding of these buildings depends on moving through trajectories that cross all thresholds.

To a moving observer, large open-plan buildings which are typical of offices floors not partitioned yet by walls and unoccupied with furniture, present a rather different case. In these environments little fragmentation exists and what does is mainly due to cores. Due to fewer spatial thresholds, the experience of moving is characterized by much longer and continuous experiences of perceiving the same edges or faces. A few and simple trajectories are sufficient for a full understanding of these environments. The moving experience is primarily characterized by the length of trips, by distances themselves rather than changes that have occurred during covering distances. By completing lengths of trips across large open buildings, a moving observer experiences size, length, metric inertia, and the energy and effort needed to cover distances.

There exist a direct connection between metric distances covered inside large open-plan floors and the number of future workspaces and secondary circulation paths. Given a uniform distribution of sizes of workstations, a long path or a future circulation segment would potentially connect more circulation segments. This differentiation between distances drawn inside a floor justifies the differentiation of axial depths and integration in layouts. Hence, there is an obvious link between metric distances drawn over a shape and syntactic features of layouts that can be accommodated in them. In his investigation on how the geometrical order is internalized in the structure of graphs of axial lines in urban environments, Hillier (1999) recognizes the length of line as one of the two major features that negotiate the internalizing of geometrical order into the structure of graphs. The metric length of the line is translated into the graph structure as a distinct set of connectivities with direct consequences to the integration of the line.

Area and shape are two characteristics of floorplate that support many descriptive concepts about building floors. We tend to associate the first with quantitative aspects of number of workstations, construction and maintenance costs, and value. The area determines at a great deal what functions can be accommodated in buildings. In the other hand, the notion of shape is linked to qualitative aspects of buildings. Between two buildings with the same floor area, the one with elongated floorplate provides an added value to activities that rely on proximity to perimeter, whereas, the one with a compact floor suits functions that require energy conservation, enclosure and proximity between locations. In contrast to measurement of area, there are no exact and implicit ways of describing shape, specifically with regard to distances contained in the shape.

The obvious ramification of combining the two notions of *area* and *shape* is the ability to define the kinds of *internal metric distances* afforded by the floorplate, which despite a primarily qualitative nature, are yet quantifiable. As discussed earlier, studies of Krasil'nikov, Tabor and Willoughby showed how floorplate shapes affect the total length of trips between workspaces. The distance between two points is defined as the shortest connection between them falling fully inside the shape. For a given area, as the floorplate shape stretches from compact to elongated, distances between points become more differentiated (**figure 5.1**). While controlling for size by keeping constant areas, the differentiation among distances is a direct and obvious effect of shape and just shape. A new description of shape which is based on metric distances is proposed. Distances are not just consequences of shapes; they are what define a particular feature of shapes. It is asked how distances are affected by shape and how distances can be used to characterize shape following an inside-to-outside format, hence contrasting to Tabor and Willoughby's perspective of distances as effect of shape.

This property of shapes is measured by summing up all metric distances between a large numbers of random points. For practical reasons, the sum of distances between pairs of random points are approximated with the taxicab grid distance between points that are spread uniformly over a shape according to an orthogonal uniform grid, i.e. the distance between centroids of tessellated tiles in the shape. These tiles, or shape units, are termed *occupation units* (*o-units)* as they correspond to the area in the floorplate needed for the future occupation functions.

The proposed measure of *grid distance (gd(ij))* is the shortest grid or taxicab distance between two o-units. The *Grid Distance (gd*) for a shape as a whole is computed as the sum of grid distances between all pairs of tiles on the floorplate. **Figure 5.2a** and **5.2b** show the grid distances of all tiles from a particular tile on a shape, and **figure 5.2c** shows the aggregate grid distances for each tile.

$$gd = \sum_{i=1,j=1}^{i=n,j=n} gd_{ij} \tag{5.1}$$

where gd_{ij} is the grid distance between two o-unit tiles i and j, and n is the total number of tiles in the shape.

The calculations of grid distance gd(ij) for one unit and aggregate grid distance gd for the entire shape are algebraically identical to the calculations of individual depths and the total depth in the *p-complex* of Hillier (1996). However, here o-units represent locations in the shape rather than partitions in a p-complex of spaces and the shape coincides with the silhouette of Hillier's cell arrangement. In Hillier's model, when shapes are wrapped onto torus by joining the left edge to the right, and the top edge to bottom the effect of proximity to center or periphery is removed, while differences remain between different shapes, (**figure 5.3**). These differences have been attributed to the *effect of shape*. It seems that what Hillier means by the *effect of shape* is the elongation or the general proportion of the shape, which is indeed the bounding contour or the *hull* of the shape. This phenomenon, while being observed by Hillier, has not been used to propose an index that captures a distinct feature of shape based on this difference. I suggest that, in addition to the *hull* of the shape, another characteristic of shape, of equal importance, is the condition resulting from the local configuration of indents or holes, their size and their proximity to the perimeter or to the center of the shape. The calculation of the proposed measure of *grid distance* takes into account inseparably the two notions of the proportionality of the perimeter and the condition of indents and holes in relation to the perimeter or center.

The measure is affected from the size of the tessellated o-unit. It is necessary to propose a way to disregard the actual size of o-units in order to characterize and compare shapes of different sizes, A theoretical shape is analyzed according two representations: first, with a coarse grid of 6 o-units, (**figure 5.4a**); and second, with a finer grid of 28 o-units (**figure 5.4b**) to inquire whether there exists any consistency between two reresentations. According to the 6 unit representation, region A, covered by 1 o-unit, has a gd of 15, whereas region C has a gd of 11, (**figure 5.4c**). According to the 24 unit representation, region A, covered by 4 o-units, has a combined gd of 140+128+120+108=496, whereas region B, covered by 4 o-units, has a combined gd of 104+92+92+80=368. The comparison of combined gd values between regions A and B calculated with two different representations shows that: for 6 units tessellation A6:B6=15:11=1.364, whereas for 24 units tessellation A24:B24=496:368=1.348. Different ratios reveal that changing the grain of representation does not maintain equal degrees of differentiation between regions in the shape.

The effect of size of representation is removed by comparing the shape under consideration with a square of equal number of representation units. The proposed measure of *Relative Grid Distance (rgd)* expresses grid metric distance as a ratio to the distance that would be obtained for a square with the same number of units.

$$rgd = \frac{gd}{gdSq} \tag{5.2}$$

where gdSq is the approximated gd value of a square with the same number of units.

For a square of side m and area m^2, gd(m^2) is given by the function[1]:

$$gd(m^2) = m^2 * \sum_{i=1}^{m} i^2 (i-1)(-0.5)^{m-i} \tag{5.3}$$

Since squares do not exist for values of n which are not square numbers, the *gdSq* value for an arbitrary number n is calculated based on a polynomial approximation of the curve linking the

[1] The function A(m) is defined as the ratio between gd(m^2) and the number of units in a square with side *m*

$$A(m) = \frac{gd(m^2)}{m^2}$$

The following relation has been discovered:

$$A(m) + 0.5 * A(m-1) = m^2 (m-1)$$

Solving the recursive function:

$$A(m) = m^2 (m-1) - 0.5 * A(m-1)$$

$$A(m-1) = (m-1)^2 (m-2) - 0.5 * A(m-2) ....etc.$$

results in the following formula for the function A(m):

$$A(m) = \sum_{i=1}^{m} i^2 (i-1)(-0.5)^{m-i}$$

from where:

$$gd(m^2) = m^2 * \sum_{i=1}^{m} i^2 (i-1)(-0.5)^{m-i}$$

values produced by gd(m^2). For an even finer approximation the series produced by the gd(m^2) function is split into five value intervals (**figure 5.5**) and gdSq is computed based on the polynomial approximation of the interval which contains n (**table 5.1**). With the exception of circular shapes, the measure of rgd is equal or bigger than 1.

A greater value of rgd shows more concavity and elongation of the shape. **Figure 5.6** shows values of rgd for eight theoretical shapes. Relative Grid Distance is a measure of compactness of the shape. It is based on the universal metric distance which is associated with metric inertia and walking effort.

5.2 Convex Fragmentation: Measuring Floorplate Shapes with Overlapping Convex Depths

The circulation system in a building facilitates the connection between its locations by means of extending convexity. The spreading of constant depth is the defining feature of circulation spaces. Two locations in a convex relationship with each other have the same depth when viewed from any location. To a moving observer, changes of direction of travel are associated with the kinetic directional inertia.

While convex floorplates inflict no constraint on a system of circulation introduced into them, floorplate shapes that depart from the convexity due to existence of wings and holes are likely to add a degree of concavity onto the circulation of the overlaid layout. Hence, the convex fragmentation of shape may allow gauging how far a shape has affected the nature of the overlaid layout with regard to increasing the number of directional changes.

The two shapes discussed earlier, (**figure 5.7**) are compared this time from the perspective of the number of orthogonal directional changes needed to travel between two points in the shape. While in the convex shape all connections between points occur without changes of direction, in the fragmented shape, some connections need 1 or 2 directional changes. Attributing the difference in directional changes to the disparity between the two shapes, a new index of shape is measured by summing up all directional changes that the shape can afford. In actual buildings, most corridor systems are organized along two major axes. Hence, from the infinite possible directions that pass through locations in a shape, two orthogonal axes are chosen as guide rulers. In contrast to the isovist integration (Turner & Penn 1999), the depth calculation for convex fragmentation takes into account only directions parallel to orthogonal axes.

At a second level, floorplate shapes are analyzed considering the entire shape as composed of circulation units (c-units). For practical reasons, the sum of directional changes between pairs of large numbers of random points is approximated with the sum of directional distances between all points uniformly spread over a shape according to an orthogonal equidistant grid. These points are centers of c-unit tiles of the tessellated shape.

When *c-units* belong to the same convex circulation space they share the same depth from a given reference point. Each time this condition is not satisfied, like in the case of turns, a depth increase occurs, (**figure 5.8**). The representation of shapes in two ways with o-units and c-units according to a dynamic model has been developed based on the issue of maintaining convexity in Hillier's experiments with permeability complexes (1996). A further description of the argument is given in Appendix 3.

The proposed measure of *Overlapping Convex Depth (ocd)* of a shape is calculated by summing up depths *ocd(ij)* between any two locations on the floorplate, (**figure 5.9**). All circulation c-units within a convex area are set to have zero distance between them. C-units in other convex areas are set to have a depth value equal to the number of maximal overlapping convex spaces that must be traversed in order to reach the convex space that contains them.

$$ocd = \sum_{i=1,j=1}^{i=n,j=n} ocd_{ij} \tag{5.4}$$

The analysis of shapes with c-units reveals distinct areas where c-units have equal ocd(i). In contrast to the analysis with o-units where areas with low gd(i) values lay around the gravity center, here areas with low depth are disjoint from each other and are scattered across the shape corresponding to the junctions of the wings and turns. These regions are termed *hot spots* because of their unique potential with regard to organizing the circulation in the shape, (**figure 5.10**). The junctions from where all the regions and wings in the shape are in linear access have ocd equal to 0. The depth value of a region increases as more areas in the shape fall in a linear shadow from it.

Hot spots act as pivot points for generating circulation systems into floorplates and they regulate how a circulation systems can be enhanced into floorplate shapes. A full description of the experiments and the seven proposed principles are given in Appendices A4 and A5.

The same theoretical shape, (**figure 5.11**) is represented in two different tessellations of 6 c-units and 28 c-units to gauge the effect of unit size on the ocd measure. For a representation with 6 c-units, the aggregate ocd values covering the region A is 2*4=8; region B is 1; and their ratio A:B = 8:1=8. For a representation with 28 c-units, A ocd=8*16=128; B ocd=4*4=16; ratio A:B=128:16=8. This proves that ocd is a function of the size of the tessellation unit, hence there exists a way to accurately disregard its effect. The measure of ocd has a built-in component of the number of c-units. The effect is twofold: first, the convex overlap depth ocd(i) of each c-unit reflects how many c-units have a certain depth from it; second, each c-unit adds its individual depth ocd(j) to the aggregate measure of ocd. The effect of the number of c-units is taken out twice, dividing ocd by the number of c-units to the power of 2.

The modified measure of the *Convex Fragmentation (cf)* gauges the extent to which the floorplate is divided into different overlapping maximal convex areas (i.e. there are no convex areas which are subsets of larger convex areas). It is calculated by the formula:

$$cf = \frac{ocd}{n^2} = \frac{\sum_{i=1,j=1}^{i=n,j=n} ocd_{ij}}{n^2} \qquad (5.5)$$

where ocd_{ij} is the overlapping convex depth between two c-units i and j, and n is the total number of c-units in the shape.

The measure of cf and is always bigger or equal to 0. The value 0 indicates a convex shape, whereas larger values show the fragmentation in the shape due to indents, existence of wings or holes. **Figure 5.12** shows the value of cf for some theoretical shapes.

The analysis of shapes with rgd and cf has been carried out using *Qelizë*[2], a Java applet developed as part of this research and currently accessible at http://www.prism.gatech.edu/~gt7531b/Qelize/qelize.html. The applet is described in the Appendix 6.

[2] Qelizë means "cell" in Albanian.

5.3 A Typology of Office Buildings Based on Relative Grid Distance and Convex Fragmentation of Floorplate Shape

A sample of 50 actual floorplates is analyzed by representing their shapes with fine modular grid tiles of o-units and c-units and calculating the two proposed measures (**figure 5.13**). The actual floorplates, listed in **table 5.2**, have been selected so as to ensure the availability of published plans of some of the layouts actually accommodated in them, which are analyzed in the next chapter. The sample includes A further description on these floorplates is given in the Appendix 1. **Figure 5.14** shows how the sample is distributed according to the measures of rgd and cf introduced earlier. **Figure 5.15** shows floorplate shapes placed over their corresponding data points in the scatterplot. Compact shapes are situated in the bottom left region. As we move upwards along the fragmentation y-axis we find shapes with a greater number of small internal cores. Moving up and towards the right, we find shapes with larger cores. By and large, the sample includes only a few very elongated and fragmented floorplates on the upper right extreme and some elongated floorplates in the lower right extreme. For the most part, fragmentation arises as a result of relatively small indentations along the perimeter or the placement of internal cores within a relatively compact convex shape-hull. Given this characteristic of the sample of floorplates, there is a significant correlation between the two measures of shape ($r=0.625$, $p= 0.000$). This correlation is descriptive of an empirical characteristic of the office building type and not a result of mathematical necessity. Shapes of office floorplates, as being affected by issues of lighting, structures, code compliance and building cost, occupy a specific zone in the family of possible shapes.

The statistical clustering of the sample according to rgd and cf shows the existence of 6 groups of closely related data points. Accordingly, a new classification into six types of floorplate is proposed based on combined degrees of rgd and cf of their shape:

1) *compact blocks external core* (rgd<1.2 and cf<0.5).

It includes floorplates with compact shapes and those with external cores and a few and small internal cores.

2) *bars* (rgd>1.2 and cf<0.5).

It includes floorplates with elongated rectangular shapes and external cores.

3) *deep space small central core* (rgd<1.2 and cf>0.5).

It includes floorplates with internal cores where dimensions of cores are relatively small in comparison to the depth between core and perimeter. The increase of cf, moving vertically along the y-axis is associated with a greater number of internal cores.

4) *shallow space large central core* (1.2<rgd<1.4 and 0.5<cf<1).

It includes floorplates with ring-like configurations of shapes with large holes, which correspond to large cores in high-rise buildings, central atria and internal courtyards.

5) *pavilions* (1.2<rgd<1.4 and cf>1)

It includes floorplates with distinct pavilions and floorplates with many large internal cores or atria.

6) *wings* (rgd>1.4 and cf>0.5)

It includes elongated foorplates broken into distinct wings.

5.4 Conclusions

In this chapter, two descriptions of shapes were proposed: the Relative Grid Distance (rgd) and Convex Fragmentation (cf). The Relative Grid Distance gauges the compactness of the shape and is calculated by comparing the aggregate of grid distances between all units in the shape to the aggregate of grid distances between all units of a square with the equivalent number of units. The conceptual foundation of this description is derived from the affordance of shapes for given metric distances. Low values of rgd, close to 1, correspond to compact floorplates where little differentiation exists among distances. Greater values of rgd correspond to elongated and broken shapes where distances in the shape are more differentiated.

The Convex Fragmentation measures the convexity of the shape and is defined based on aggregate changes of directions, according to two main orthogonal axes, between units in a shape, i.e. the number of boundaries between containing convex spaces crossed to reach from one unit to another. This description was based on the directional changes as constituting the primary experience of moving across the circulation system. Low values of cf denote floorplates that approximate convex shapes, while greater values of cf correspond to shapes with wings and holes.

Calculations were performed using a Java computer application developed for this purpose. The dynamic nature of the proposed model, where units of shape can acquire different conditions of occupation spaces and circulation spaces, enabled experimentations of carving circulations out of shapes and enhancing basic circulations into floorplate shapes.

The analysis of shapes from the viewpoint of Convex Fragmentation revealed the existence of distinct regions of shapes composed of units with equal depth and with depth distinctly lower than their surroundings, located at the intersections of major wings of the shape. These locations, termed hot spots, were demonstrated to be crucial for placing integrating circulation systems as backbones for future layouts as well as understanding the complex relationship between two-dimensional elements of shape and one-dimensional elements of circulation system. There emerged a clearer picture of how configurational concerns showed up relationships between the particular nature of circulation and occupation spaces. The intrinsic feature of circulation systems which facilitates linear movement was used as the foundation for the analysis with circulation units that extracted from the shape the potential to generate a complex of connected segments of circulation. Connecting hot spots according to their depth rank, guaranteed the construction of the most integrated circulation system to be inserted in the shape. This also estimated the effect of floorplate shapes on the overall structuring of layouts; fragmented shapes would dictate by and large aspects of layouts in contrast to neutral convex shapes that little affect the outcome of layout. In a second facet, the implication of hot spots was also demonstrated by principles of generating shapes by enhancing basic circulation structures. The organizing effect of circulation extended throughout the shape by creating stripes aligned to circulation segments and relatively more integrated.

In contrast to indices of shape proposed by studies in geography and geometry, the measures proposed here were conceived and calculated based on the principle of from-inside-to-outside according to which, relations between locations in the shape are aggregated to produce its overall picture. These relations have a configurational nature as they are based on depths between units in relation to all other units in the shape. Despite being based on local relationships between units, the two measures are global and robust and gauge features of shape in their entirety. The analysis concluded by proposing a new typology of office buildings based on combined values of rgd and cf of floorplate shapes. The next chapter will analyze a sample of actual layouts in order to distill typological features which will be used to formulate principles of ideal layouts.

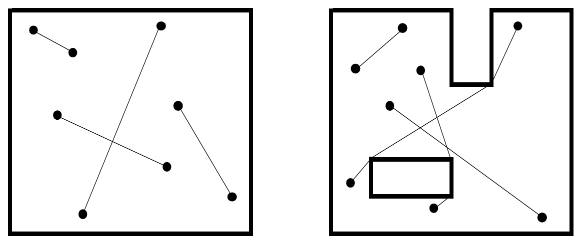


Figure 5.1: Distances as shortest connections between pairs of random points in two shapes. In comparison to the square, the shape with indents and holes affords longer distances and more differentiation between distances.

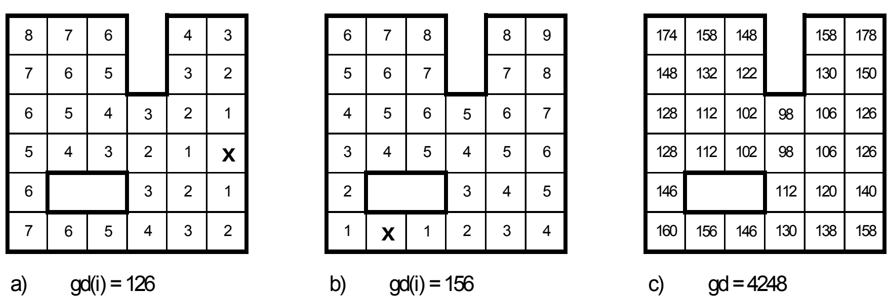


Figure 5.2: Calculation of Grid Distance gd(ij) from two o-units shown with (x) and the aggregation of Grid Distances gd(i) into the gd for the entire shape.

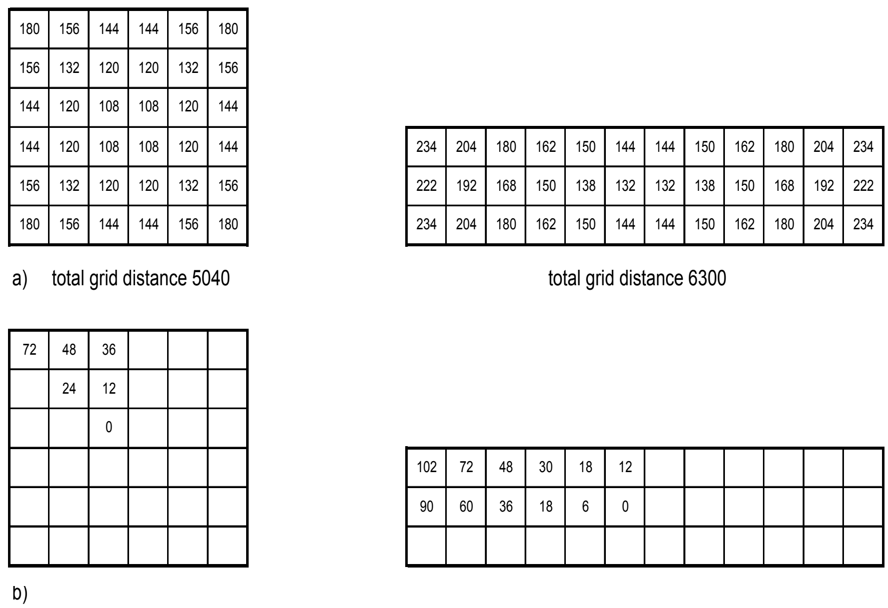


Figure 5.3: Grid distances in two shapes represented with 36 units, above; differences in grid distances after the wrapping of shapes into torus.

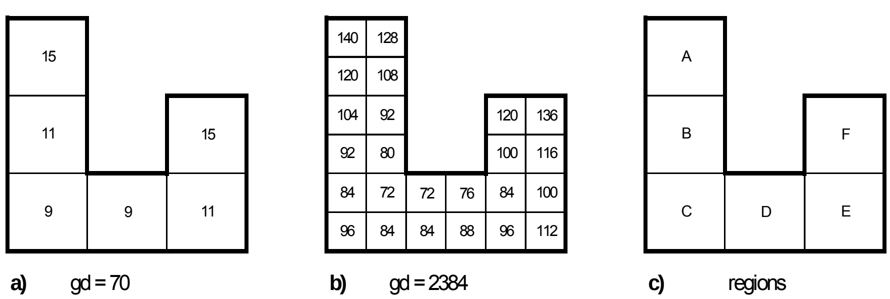


Figure 5.4: Calculation of gd for two cases: a) shape is represented with 6 o-units; b) shape is represented with 24 o-units; c) regions of shape for which combined gd values of comprising units are compared.

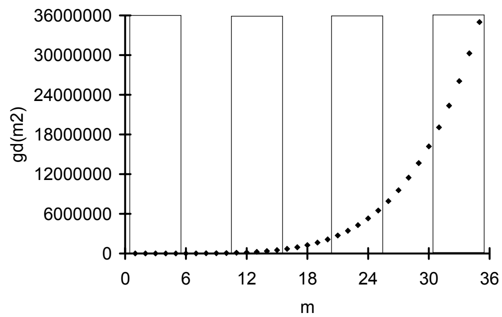


Figure 5.5: Scatterplot of the gd(m^2) function, where intervals of 5 consecutive data points are used for approximating the gdSq(n) function.

Table 5.1: Equations of gdSq(n) based on approximations with polynomial equations of the order of 4 for intervals of 5 consecutive data points of the function gd(m^2).

range of number of units (n)	gdSq(n) equation
1 - 25	$gdSq(x) = 13.3x^4 - 104x^3 + 386.7x^2 - 696x + 480$
26 – 100	$gdSq(x) = 26.7x^4 - 424x^3 + 3333.3x^2 - 13016x + 20160$
101 - 225	$gdSq(x) = 43.3x^4 - 1124x^3 + 14517x^2 - 93516x + 240240$
226 – 400	$gdSq(x) = 60x^4 - 2157.3x^3 + 38700x^2 - 346683x + 1240320$
401 – 625	$gdSq(x) = 76.7x^4 - 3524x^3 + 80883x^2 - 927516x + 4250400$
626 – 900	$gdSq(x) = 93.3x^4 - 5224x^3 + 146067x^2 -2041016 +11400480$
901 - 1225	$gdSq(x) = 109.9x^4 - 7257.3x^3 + 239249.9x^2 - 3942182.6x + 25970560$

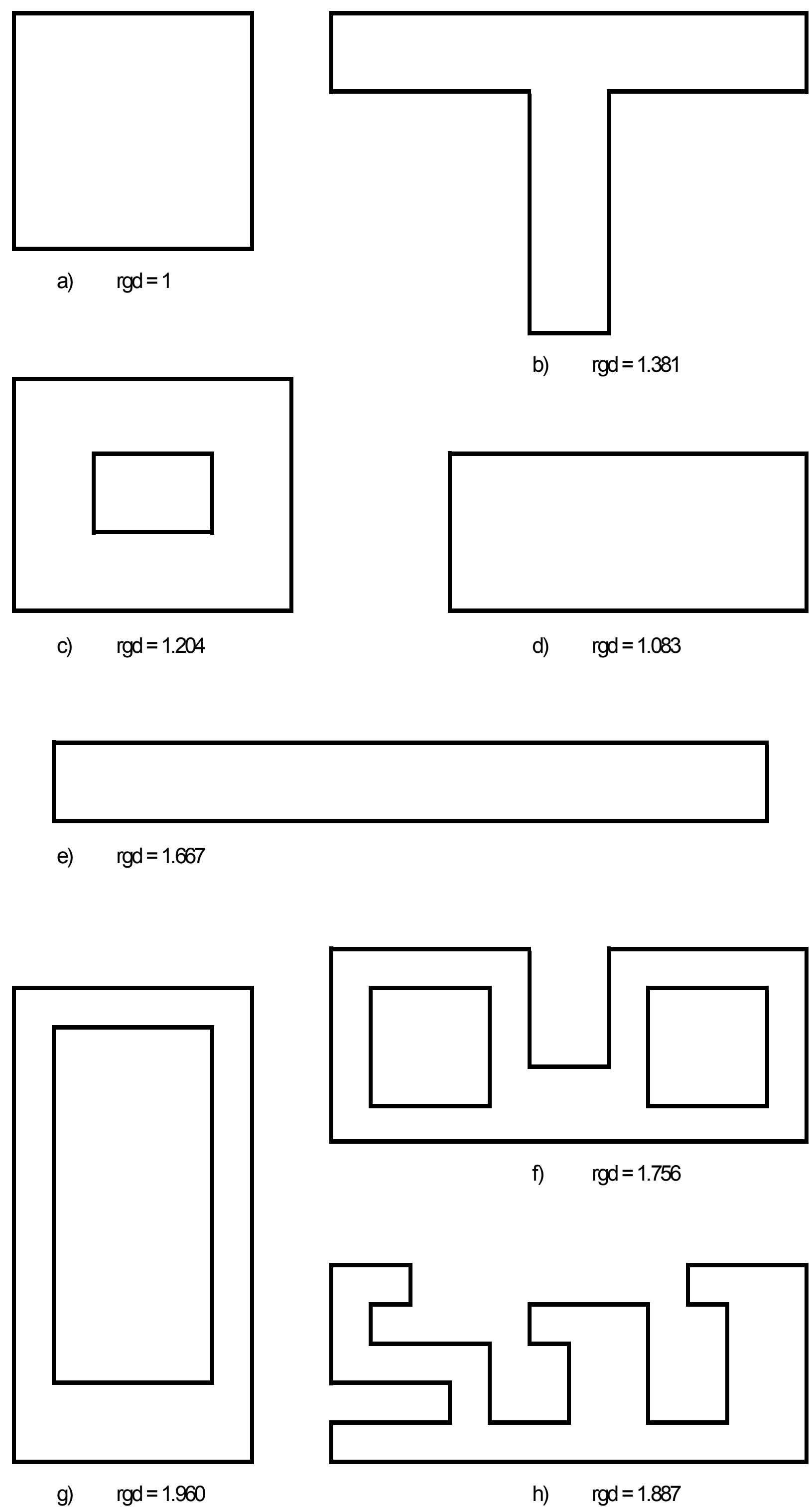


Figure 5.6: Relative Grid Distance for a few theoretical shapes.

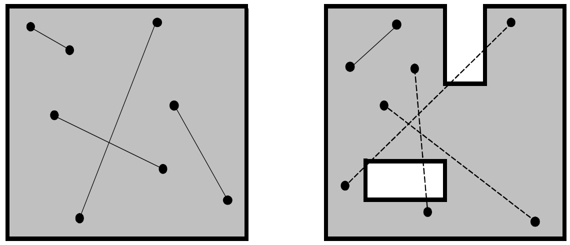


Figure 5.7: Directional distances between pairs of points in two shapes. In comparison to the square, where no convex overlap exists, the shape with indents and holes affords changes of directions between points due to the non-convexity. Dashed lines indicate connections that require convex overlap changes.

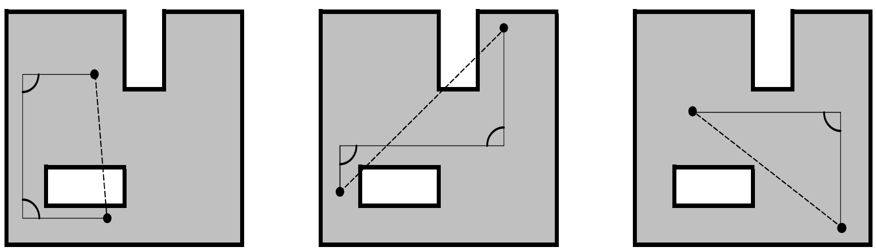


Figure 5.8: Counting the convex overlap depths needed to travel between pairs of points that do not have a convex relationship with each other.

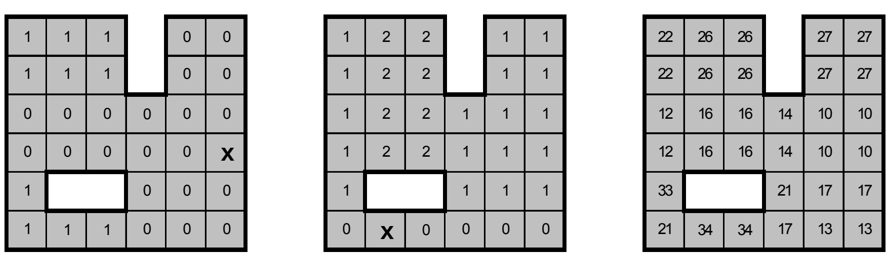


Figure 5.9: Calculation of Overlapping Convex Depth ocd(ij) from two c-units shown with (x) and the aggregation of Overlapping Convex Depths ocd(i) into the ocd for the entire shape.

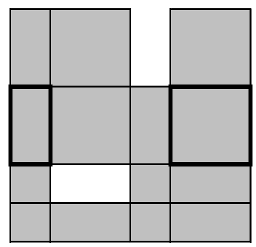


Figure 5.10: The emergence of regions where c-units have equal ocd(i) values. Hot spots, defined as regions with the lowest convex depth values, are shown with bold contours.

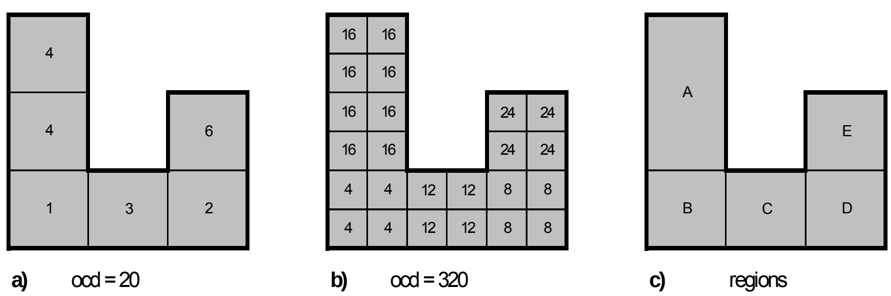


Figure 5.11: Calculation of ocd for two cases a) shape is represented with 6 c-units; b) shape is represented with 24 c-units; c) regions of shape for which combined ocd(i) values of comprising units are compared.

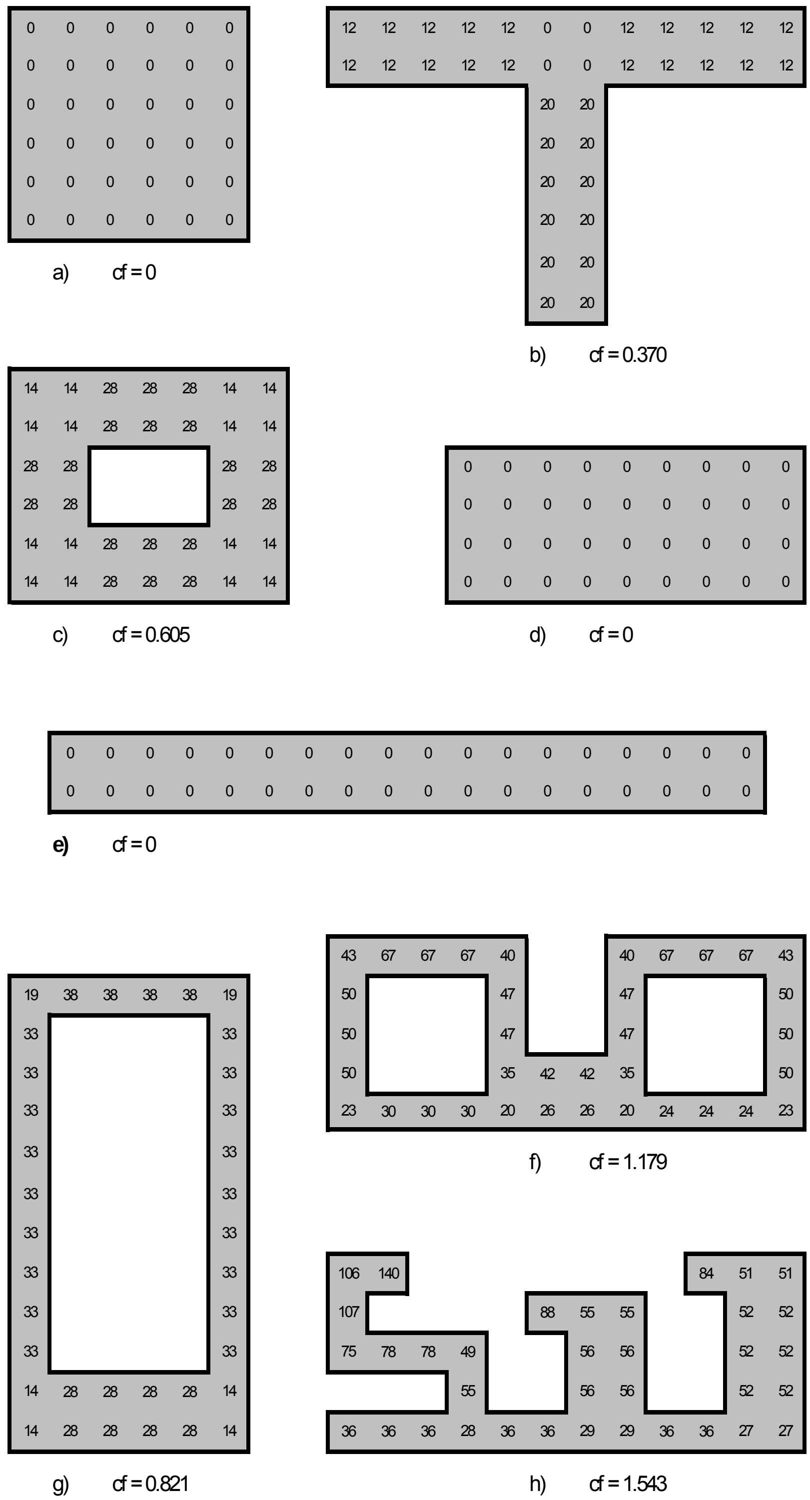


Figure 5.12: Convex fragmentation cf for a few theoretical shapes. Values of ocd(i) are shown over each shape unit.

Table 5.2: Catalogue of the sample of floorplates and office layouts.

	name	architect (shell - layout)	location
1	3com Corporation	Studios Architecture - Studios Architecture	Santa Clara, CA, USA
2	Andersen (after move)	Mies van der Rohe - DEGW & SOM	Chicago, IL, USA
3	Andersen (before move)	Unknown - unknown	Chicago, IL, USA
4	Allen & Overy	The Associated Architects - The Switzer Group	New York, NY, USA
5	Arthur Andersen	Unknown - BDG McColl	London, UK
6	Apicorp	DEGW, Ove Arup & Assoc. - DEGW	Al Khobar, Saudi Arabia
7	Apple Computer Inc.	Unknown - Gensler	Cupertino, CA, USA
8	Andersen Consulting	F. Gehry & Milunić - E. Jirična Architects	Prague, Czech Republic
9	Buch und Ton	Unknown - The Quickborner Team	Güttersloh, Germany
10	Chase Manhattan Bank	Carson, Lundin & Shaw - The Switzer Group	New York, NY, USA
11	Chiat/Day Advertising	F. Gehry & Associates - F. Gehry & Associates	Venice, CA, USA
12	TBWA Chiat/Day	Emery Roth & Sons - Gaetano Pesce	New York, NY, USA
13	Citicorp	SOM - SOM	New York, NY, USA
14	Commerzbank AG	Sir N. Foster & Partners - Sir N. Foster & Partners	Frankfurt, Germany
15	Data-Firmengruppe	Kauffmann Theilig - Kauffmann Theilig	Gniebel, Germany
16	Davis Polk & Wardwell	SOM - Gensler	New York, NY, USA
17	DEGW London Office	Unknown - DEGW	London, UK
18	Discovery Channel Latin Am.	Unknown - Studios Architecture	Miami, FL, USA
19	DuPont	Unknown - The Quickborner Team	Wilmington, DE, USA
20	The Equitable	Harrison & Abramovitz & E. Roth - Switzer Group	New York, NY, USA
21	Ford Foundation	Roche/Dinkerloo & Assoc. - Roche/Dinkerloo	New York, NY, USA
22	Ford Motor Co.	Unknown - The Quickborner Team	Cologne, Germany
23	f/X Networks	Johnson, Fain & Pereira – Fernau & Hartman	Los Angeles, CA, USA
24	Greenberg Traurig	Emery Roth & Sons, Gropius - Switzer Group	New York, NY, USA
25	Hoffmann - La Roche	The Hillier Group - Gensler	Nutley, NJ, USA
26	IBM Regional Headquarters	Unknown – The Switzer Group	Cranford, NJ, USA
27	IBM (UK) Limited	M. Hopkins & Partners / M. Hopkins & Partners	London, UK
28	IBM Australia	Buchan, Laird & Bawden - Daryl Jackson Intl.	Melbourne, Australia
29	Interpolis	Abe Bonema - Abe Bonema, Kho Ie Associates	Tilburg, Holland
30	Direct. of Telecom., MPBW	Whitehall Dev. Group - Whitehall Dev. Group	Kew, UK
31	Eastman Kodak	Unknown - The Quickborner Team	Rochester, NY, USA
32	Lend Lease Interiors	H. Seidler, P.L. Nervi - Bligh Voller, DEGW	Sydney, Australia
33	Leo A Daly	Thompson, Ventulett, Stainbeck - TVS	Atlanta, GA, USA
34	Lowe & Partners/SMS	SOM - Sedley Place	New York, NY, USA
35	McDonald’s	Heikkinen-Komonen - Heikkinen-Komonen	Helsinki, Finland
36	McDonald’s Italia	Atelier Mendini - Atelier Mendini	Milan, Italy
37	MGIC	SOM - Warren Platner Associates	Milwaukee, WI, USA
38	Nickelodeon	Kahn & Jacobs, Der Scutt - Fernau Hartman	New York, NY, USA
39	Olivetti A	DEGW, Studio De Luchi – DEGW, De Luchi	Bari, Italy
40	Olivetti B	DEGW, Studio De Luchi – DEGW, De Luchi	Bari, Italy
41	Olivetti C	DEGW, Studio De Luchi – DEGW, De Luchi	Bari, Italy
42	Orenstein-Koppel	Unknown - The Quickborner Team	Dortmund, Germany
43	Sears 40	SOM - SLS/Environetics Inc.	Chicago, IL, USA
44	Sears 70	SOM - The Environments Group	Chicago, IL, USA
45	Steelcase Inc.	WBDC, Inc. - Steelcase	Grand Rapids, MI, USA
46	British Telec., 5 Longwalk	Sir N. Foster & Partners - Sir N. Foster & Partners	London, UK
47	British Telec., The Square	Arup Associates - Arup Associates, DEGW	London, UK
48	Vitra International AG	F. Gehry & Associates - F. Gehry & Associates	Basel, Switzerland
49	Weyerhaeuser Company	SOM - Sidney Rodgers & Associates	Tacoma, WA, USA
50	WMA Consulting Engineers	Unknown – Valerio Dewalt Train & Associates	Chicago, IL, USA

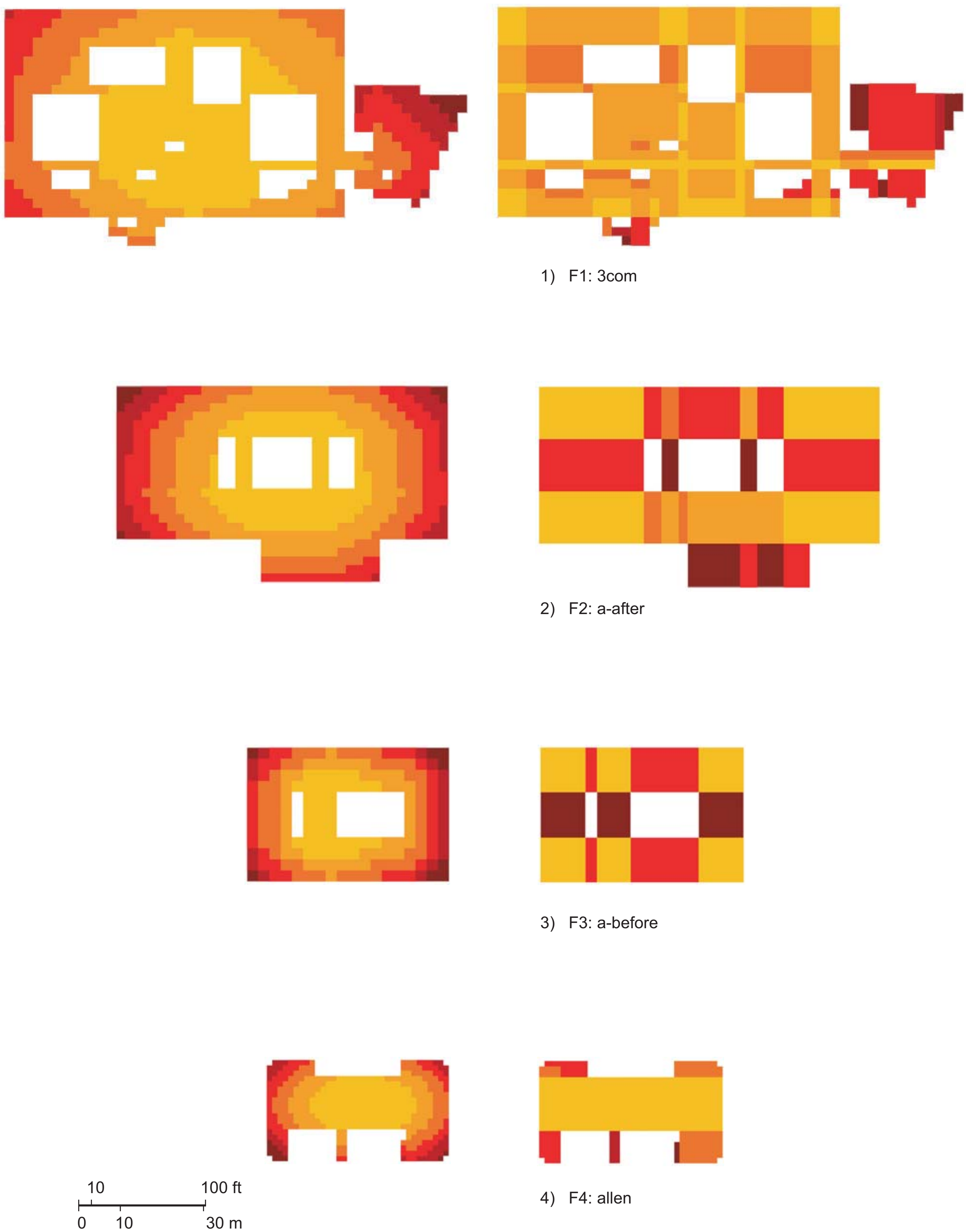
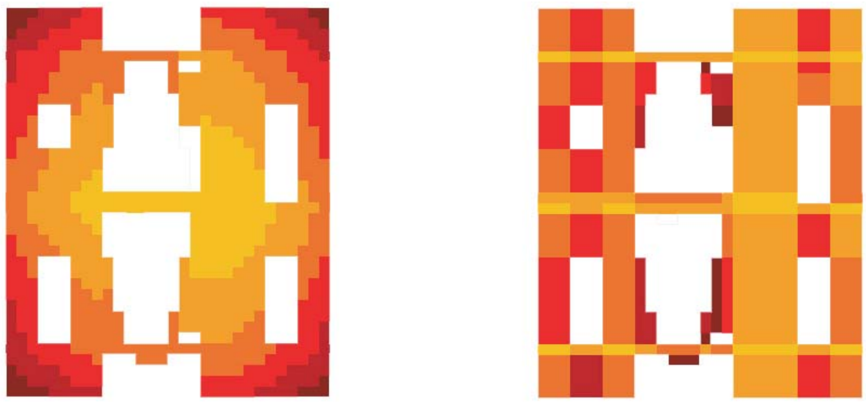
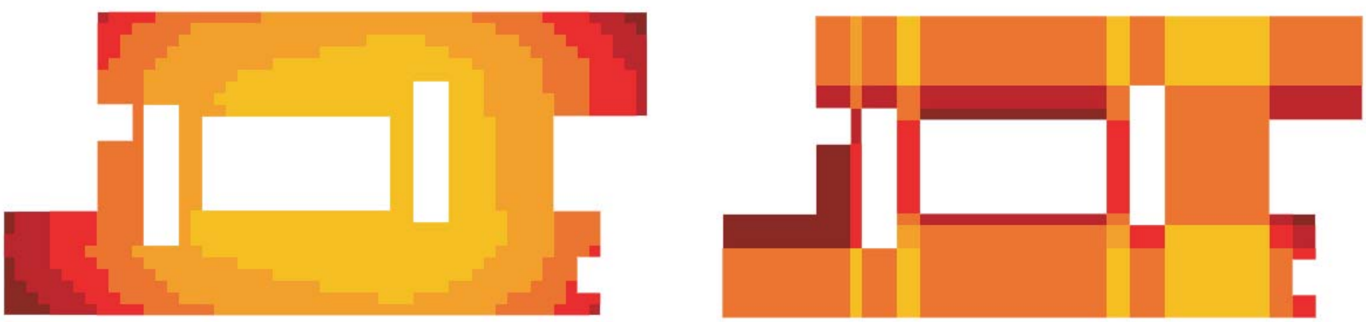


Figure 5.13: Office floorplate shapes analyzed with rgd (left) and cf (right), (F1 to F4).

5)   F5: a-london



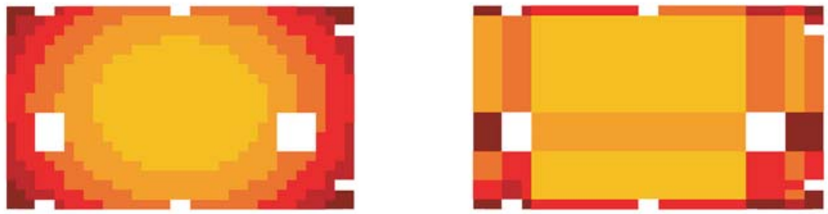
6)   F6: apicorp



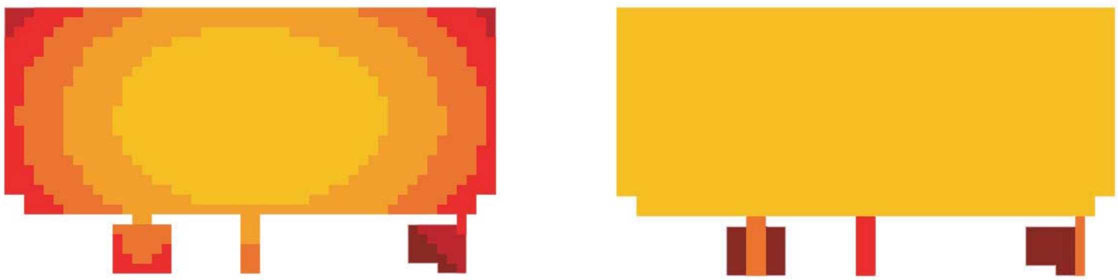
7)   F7: apple

8)   F8: a-prague

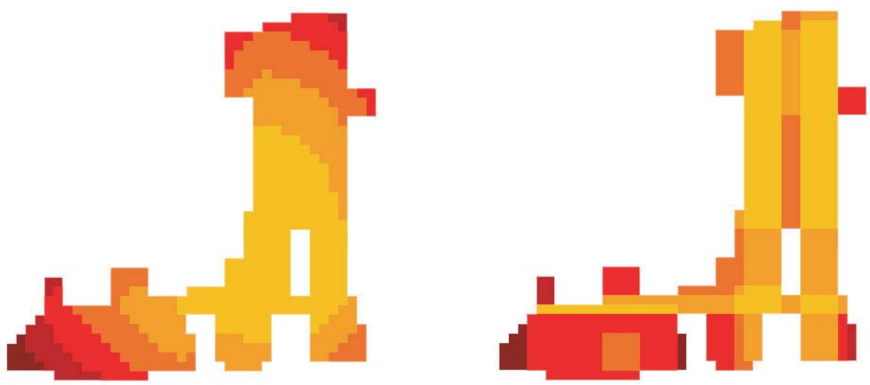
Figure 5.13 continued: (F5 to F8).



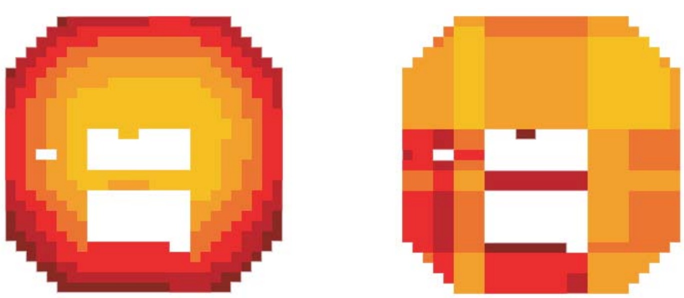
9) F9: buch



10) F10: chase

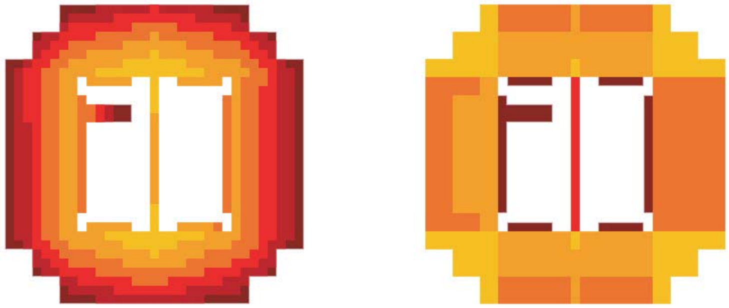


11) F11: chiat-ca

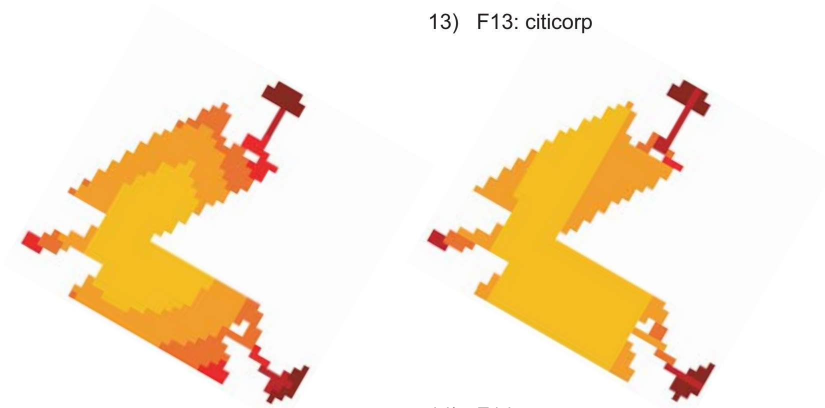


12) F12: chiat-ny

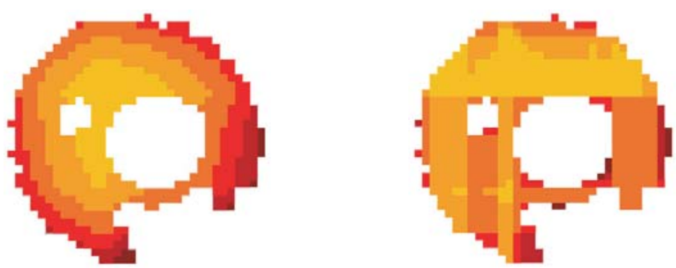
Figure 5.13 continued: (F9 to F12).



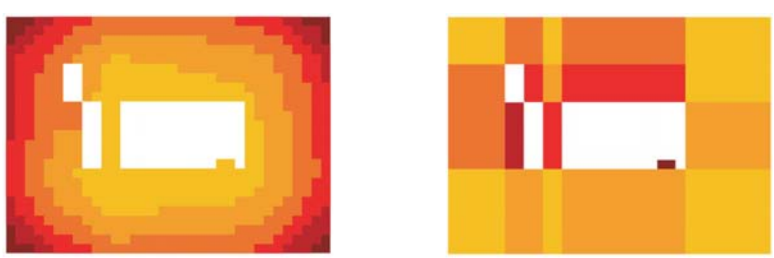
13) F13: citicorp



14) F14: commerz



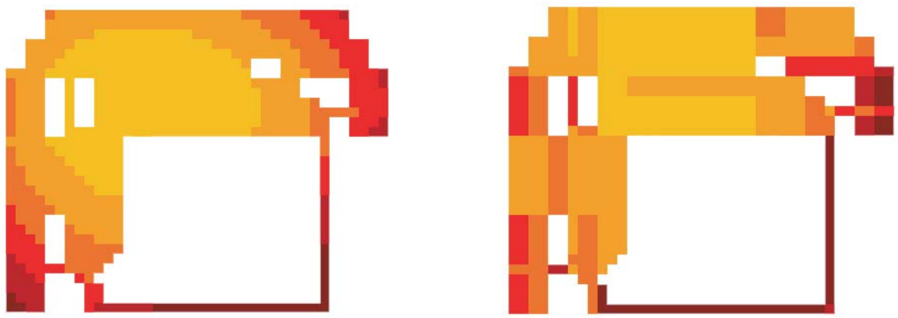
15) F15: datapec



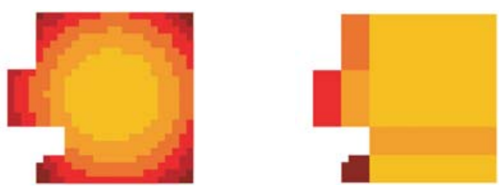
16) F16: davis

Figure 5.13 continued: (F13 to F16).

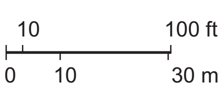
17) F17: degw



18) F18: discovery

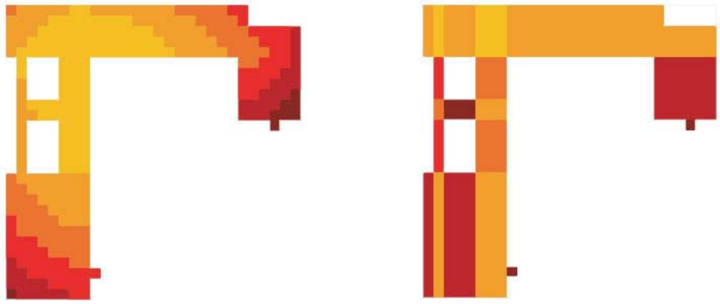


19) F19: dupont

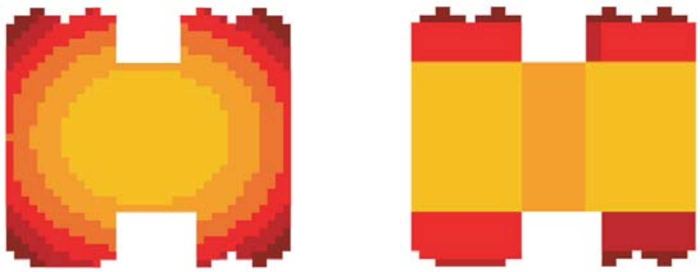


20) F20: equitable

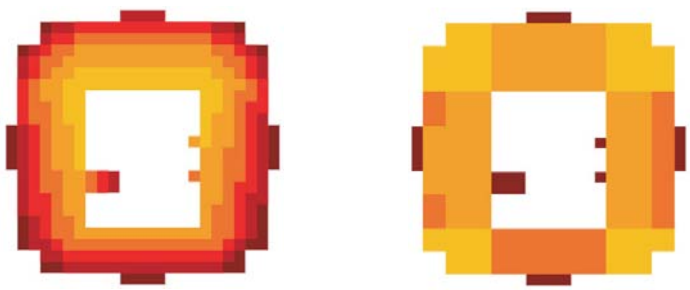
Figure 5.13 continued: (F17 to F20).



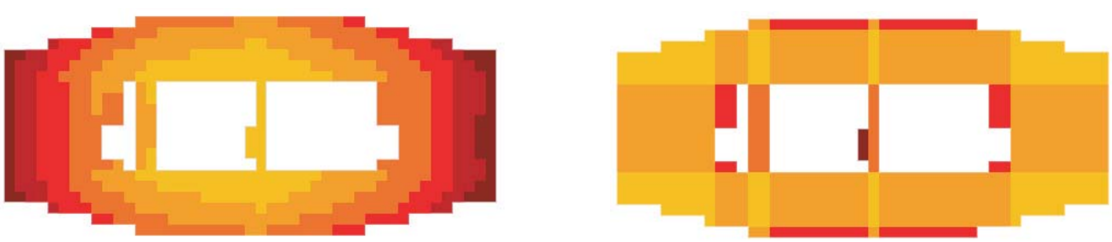
21) F21: ford-f

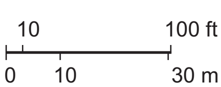


22) F22: ford-m



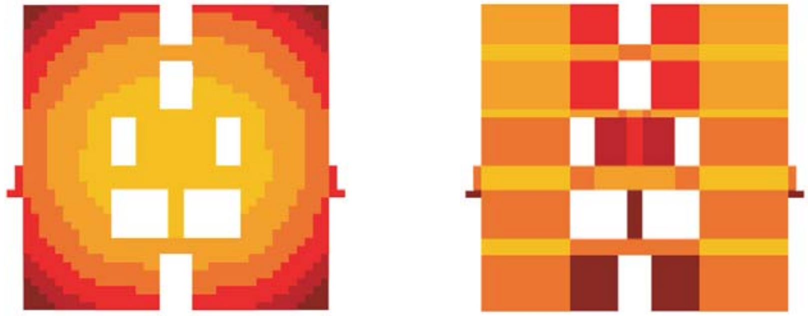
23) F23: fx



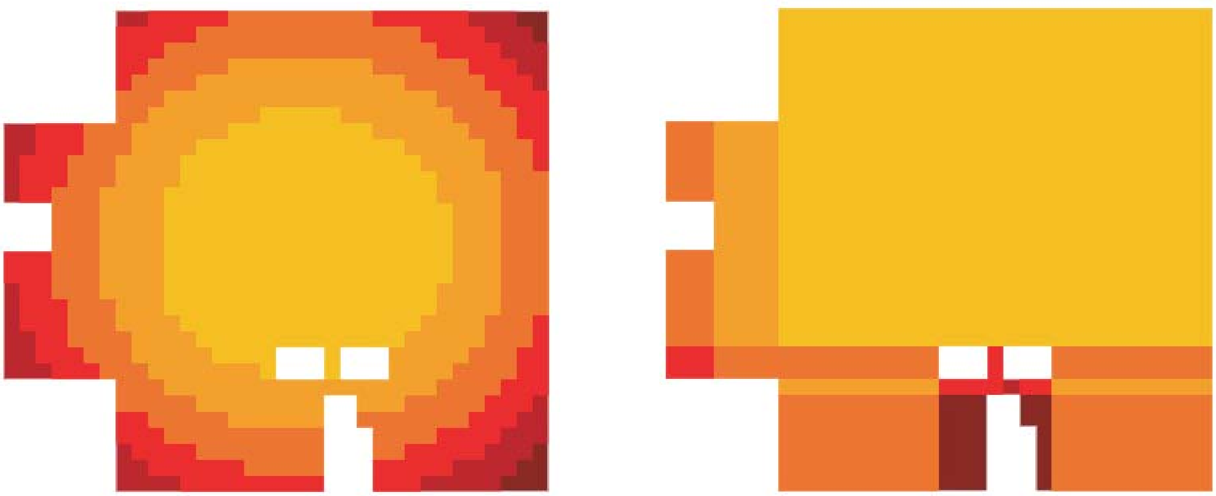


24) F24: greenberg

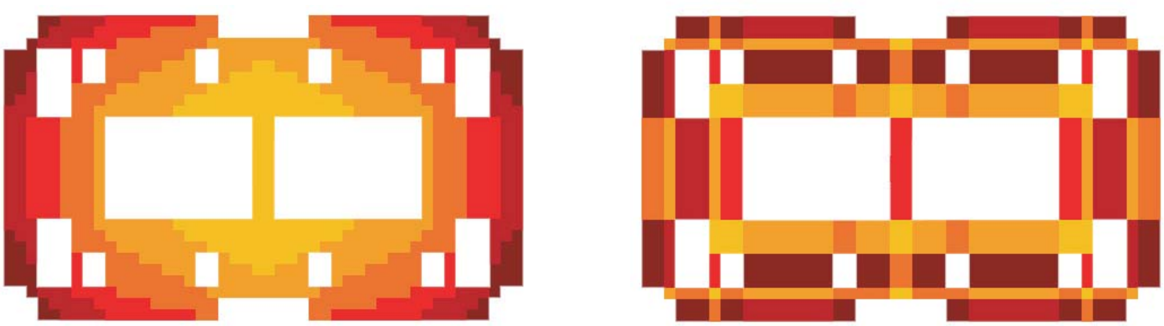
Figure 5.13 continued: (F21 to F24).



25) F25: hoffmann



26) F26: ibm-cranford

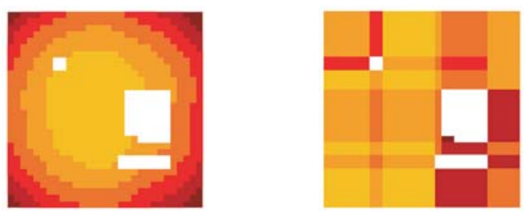


27) F27: ibm-london

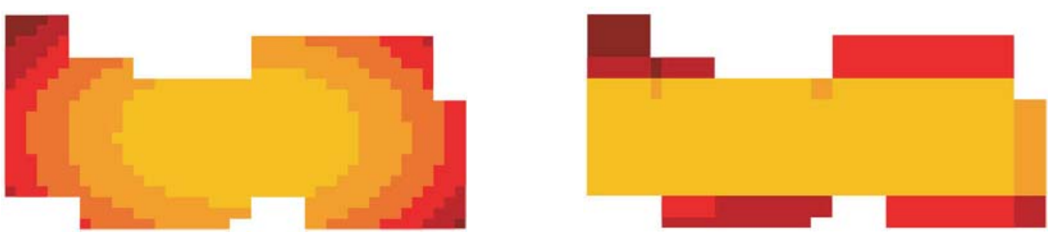
Figure 5.13 continued: (F25 to F27).

28) F28: ibm-melbourne

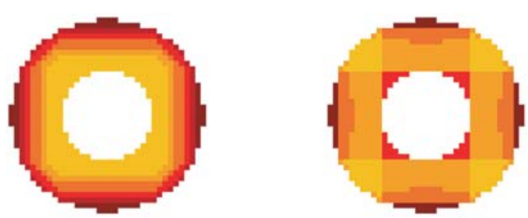
29) F29: interpolis



30) F30: kew

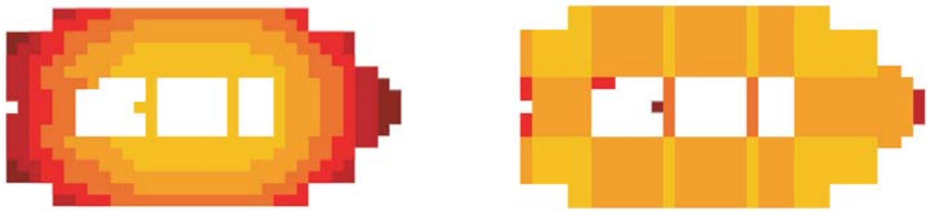


31) F31: kodak

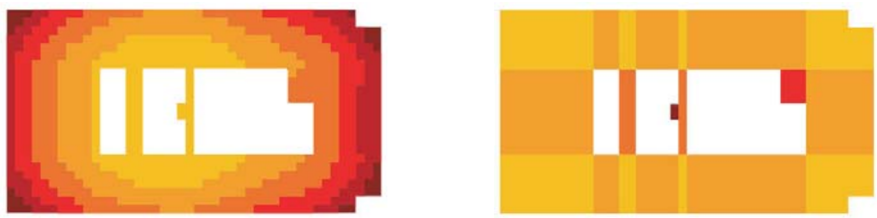


32) F32: lend

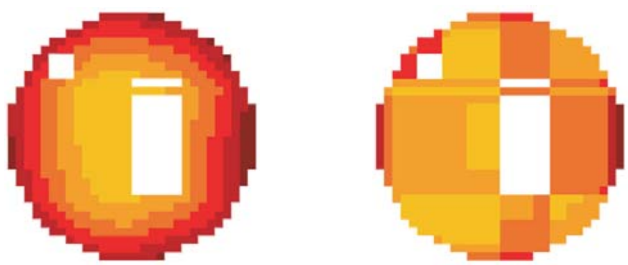
Figure 5.13 continued: (F28 to F32).



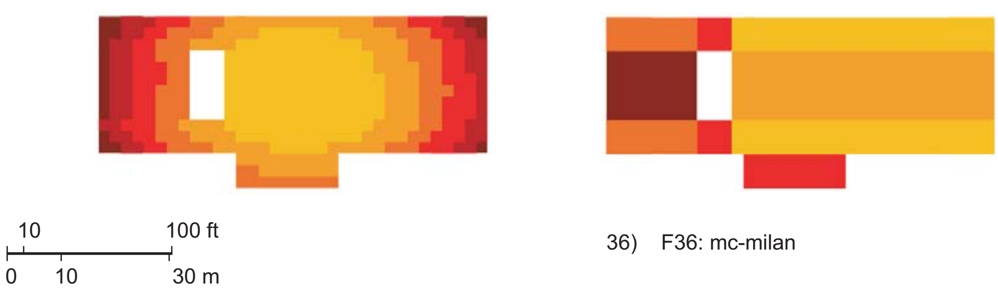
33) F33: leo



34) F34: lowe

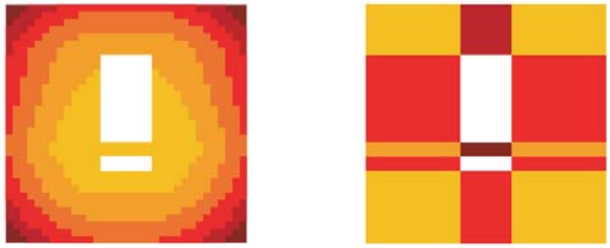


35) F35: mc-helsinki

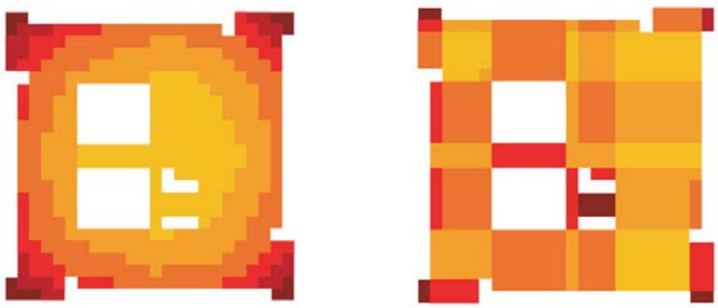


36) F36: mc-milan

Figure 5.13 continued: (F33 to F36).



37) F37: mgic



38) F38: nickelodeon

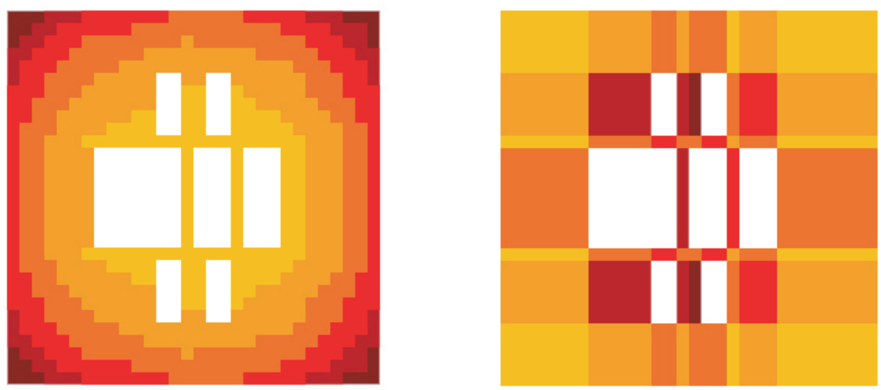
39) F39: olivetti-a

40) F40: olivetti-b

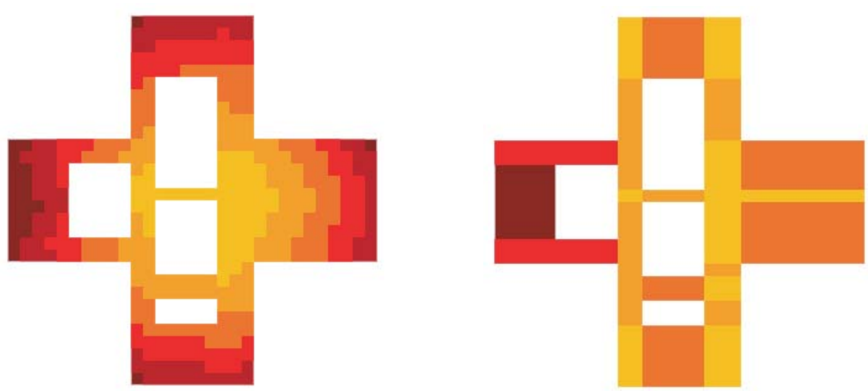
41) F41: olivetti-c

Figure 5.13 continued: (F37 to F41).

42) F42: orenstein



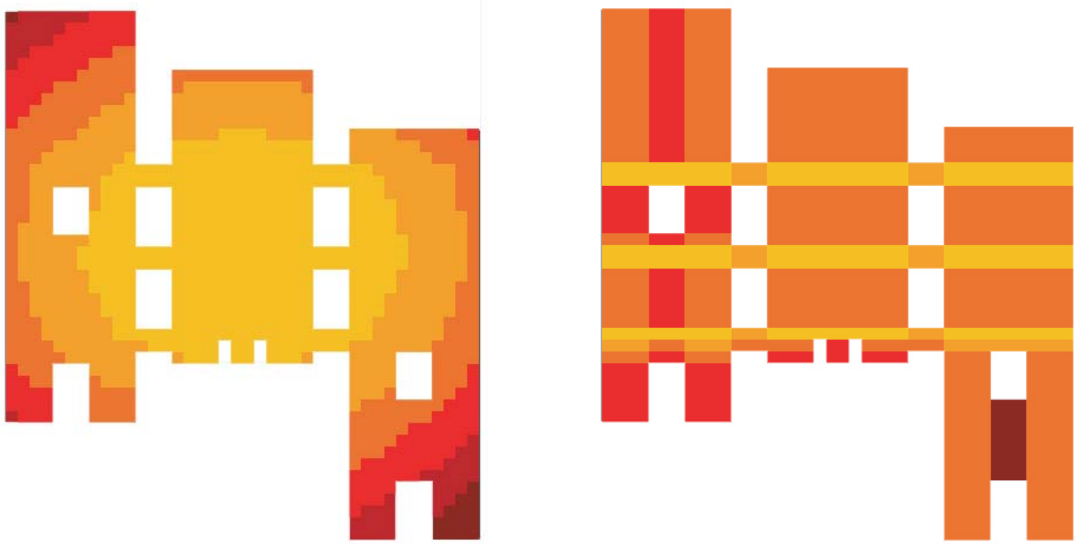
43) F43: sears-40



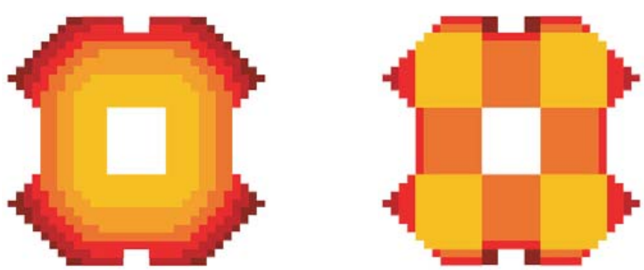
44) F44: sears-70

Figure 5.13 continued: (F42 to F44).

45) F45: steelcase



46) F46: stockley-5



47) F47: stockley-sq

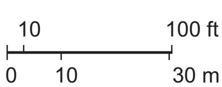
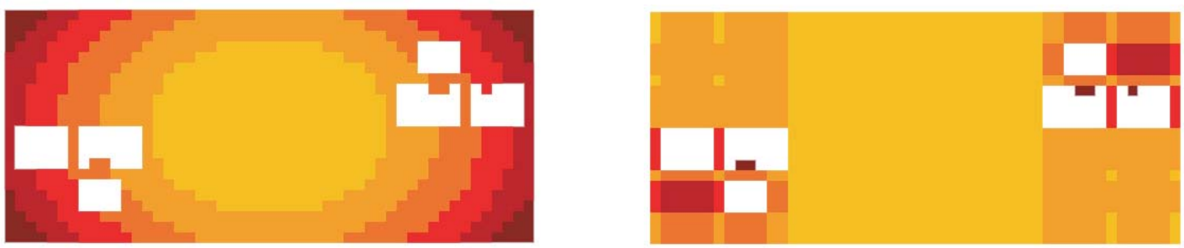
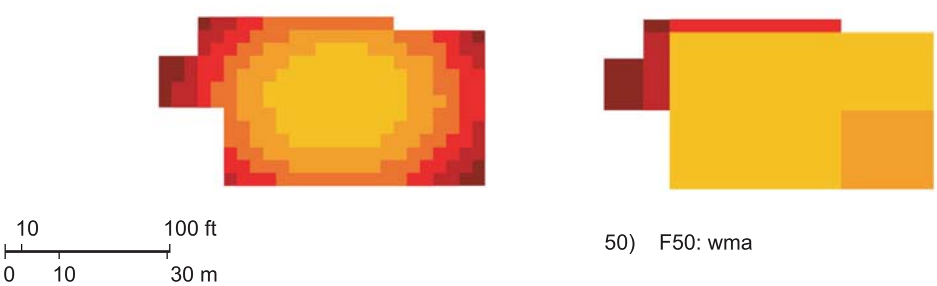


Figure 5.13 continued: (F45 to F47).

48) F48: vitra



49) F49: weyer



50) F50: wma

Figure 5.13 continued: (F48 to F50).

Table 5.3: Shape analysis of the sample of 50 floorplates.

	name	code	rgd	cf
1	3com Corporation	F1: 3com	1.335	1.534
2	Andersen (after move)	F2: a-after	1.157	0.706
3	Andersen (before move)	F3: a-before	1.173	0.657
4	Allen & Overy	F4: allen	1.221	0.440
5	Arthur Andersen	F5: a-london	1.424	0.525
6	Apicorp	F6: apicorp	1.292	1.276
7	Apple Computer Inc.	F7: apple	1.289	0.975
8	Andersen Consulting	F8: a-prague	1.189	0.968
9	Buch und Ton	F9: buch	1.060	0.458
10	Chase Manhattan Bank	F10: chase	1.104	0.207
11	Chiat/Day Advertising	F11: chiat-ca	1.613	1.529
12	TBWA Chiat/Day	F12: chiat-ny	1.132	0.802
13	Citicorp	F13: citicorp	1.280	1.007
14	Commerzbank AG	F14: commerz	1.327	1.345
15	Data-Firmengruppe	F15: datapec	1.246	1.176
16	Davis Polk & Wardwell	F16: davis	1.177	0.755
17	DEGW London Office	F17: degw	1.087	1.130
18	Discovery Channel Latin Am.	F18: discovery	1.343	1.087
19	DuPont	F19: dupont	1.010	0.189
20	The Equitable	F20: equitable	1.259	0.783
21	Ford Foundation	F21: ford-f	1.675	0.944
22	Ford Motor Co.	F22: ford-m	1.061	0.413
23	f/X Networks	F23: fx	1.273	0.912
24	Greenberg Traurig	F24: greenberg	1.338	0.932
25	Hoffmann - La Roche	F25: hoffmann	1.125	1.057
26	IBM Regional Headquarters	F26: ibm-cranford	1.019	0.436
27	IBM (UK) Limited	F27: ibm-london	1.365	1.477
28	IBM Australia	F28: ibm-melbourne	1.216	0.984
29	Interpolis	F29: interpolis	1.167	0.000
30	Direct. of Telecom., MPBW	F30: kew	1.075	0.607
31	Eastman Kodak	F31: kodak	1.167	0.399
32	Lend Lease Interiors	F32: lend	1.270	1.030
33	Leo A Daly	F33: leo	1.202	0.804
34	Lowe & Partners/SMS	F34: lowe	1.280	0.748
35	McDonald’s	F35: mc-helsinki	1.122	0.856
36	McDonald’s Italia	F36: mc-milan	1.159	0.505
37	MGIC	F37: mgic	1.104	0.586
38	Nickelodeon	F38: nickelodeon	1.160	0.849
39	Olivetti A	F39: olivetti-a	1.031	0.000
40	Olivetti B	F40: olivetti-b	1.031	0.000
41	Olivetti C	F41: olivetti-c	1.031	0.000
42	Orenstein-Koppel	F42: orenstein	1.117	0.634
43	Sears 40	F43: sears-40	1.178	0.917
44	Sears 70	F44: sears-70	1.351	1.450
45	Steelcase Inc.	F45: steelcase	1.046	0.406
46	British Telec., 5 Longwalk	F46: stockley-5	1.231	1.249
47	British Telec., The Square	F47: stockley-sq	1.094	0.681
48	Vitra International AG	F48: vitra	1.367	0.356
49	Weyerhaeuser Company	F49: weyer	1.136	0.584
50	WMA Consulting Engineers	F50: wma	1.046	0.129

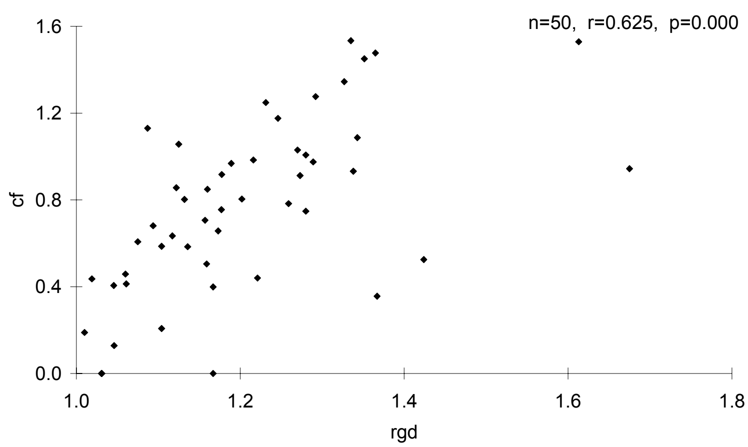


Figure 5.14: Scatterplot of cf against rgd for shapes of 50 actual floorplate.

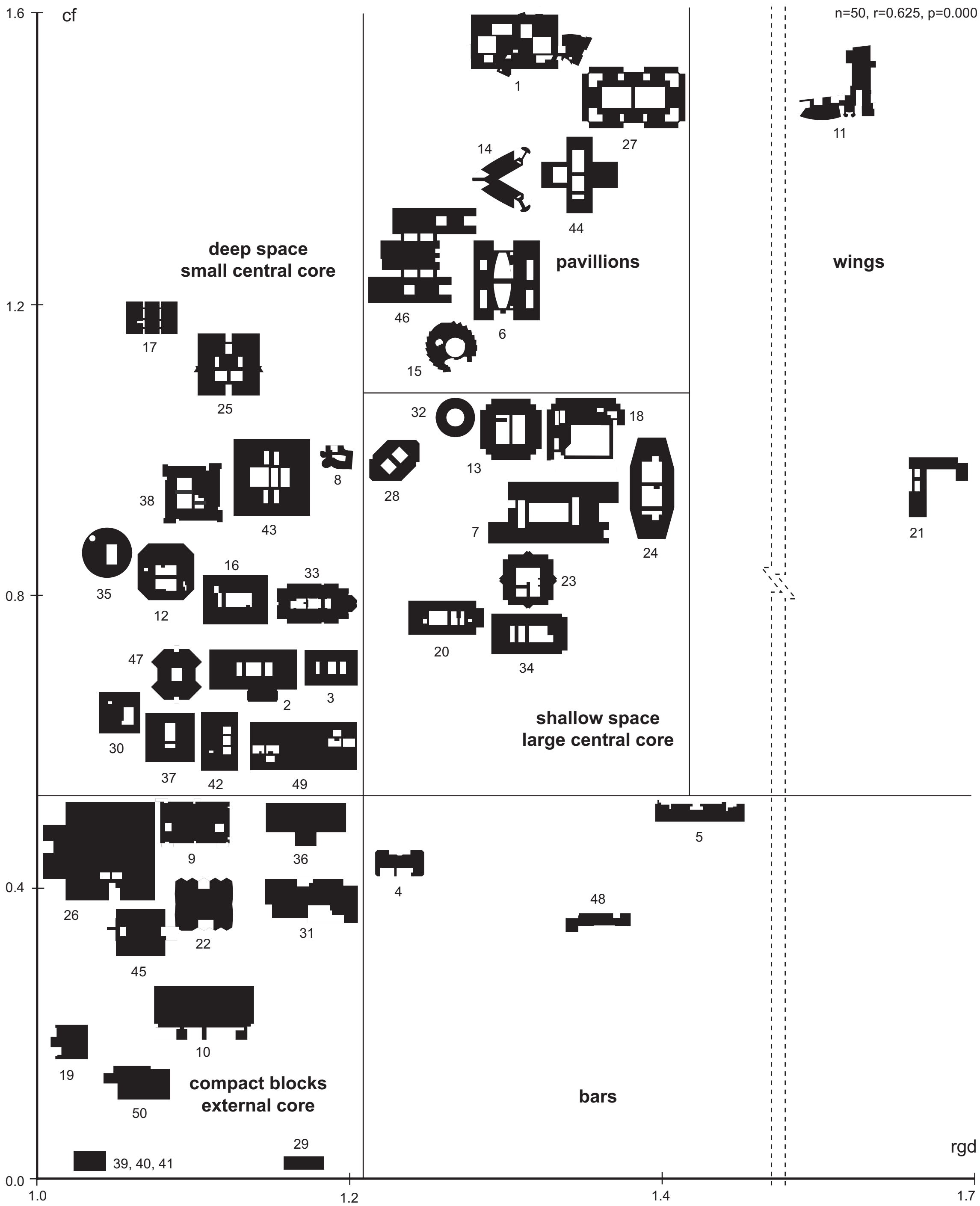


Figure 5.15: Fifty floorplates compared according to rgd and cf. Six types of floorplate are proposed according to combined ranges of the two measures.

Chapter Six

Formulating Ideal Layouts from Types of Actual Office Layout

Outline

The aim of this chapter is to formulate ideal layouts based on generation principles which are based on typological commonalities of linear map representations of actual office layouts. A preliminary heuristic inquiry about layout characteristics of a sample of fifty actual office layouts has been supported by the syntactic analysis of these layouts aimed at discerning variance patterns among layout measures, especially those affecting the layout Integration. Three types of office layouts are proposed based on degrees of connectivity bias and density of their linear map representations: biased, unbiased-sparse and unbiased-dense. Due to the considerable size of the sample, the typological classification has produced significant results. In contrast, the testing of consistent relationships between measures of layouts and measures of floorplates has aimed at enlightening the next steps of research rather than demonstrating the validity of correlations due to the multitude of factors affecting layouts as well as the reduction of the size of sub-samples after the splitting into types. The generation of ideal layouts represents the first stage of the inquiry on the effects of floorplate shapes on layouts.

6.1 A Syntactic Typology of Office Layout Types Based on Density and Connectivity Bias

This section is aimed at identifying robust typological characteristics of office layouts by distilling consistent patterns from actual layouts. The variability of office layouts is studied based on the sample of fifty published layouts (**table 5.2**) representing best practice from 1960s to the present, which are described in Appendix 1. Layouts have been represented with linear maps by drawing the fewest and longest lines over the internal circulation, which for the purpose of the thesis includes not only shared corridors, but also circulation areas inside leased space; only lines giving access to single private rooms or well defined private areas are excluded. The emphasis on directional distance differentiates this research from prior research on the effects of floorplate shapes upon metric distances (Tabor, 1976; Willoughby, 1975).

The sample of office layouts exemplifies a good variety of open plan and cellular configurations. A heuristic classification of the sample into three categories of “predominantly cellular”, “predominantly open plan” and “mixed” is carried out by taking into account the percentage of usable area covered by open plan and cellular workplaces (**table 6.1)**. The ratio of 1:4 between areas covered by the two layout types is considered as the threshold for determining the predominant type. For example, layout L37 with 27.6% cellular and 13.6% open plan is classified as ‘mixed’, whereas layout L38 with 8.5% cellular and 38.5% open plan is classified as ‘predominantly open plan’. There are 8 “predominantly cellular” layouts, 26 “predominantly open” layouts and 16 “mixed” layouts in the sample.

The search for layout typological commonalities has addressed geometrical features of density of lines, consistent angles of intersection and the density of intersection per each length unit. A heuristic examination suggests two fundamental dimensions of variability: First, while some layouts are characterized by dense patterns of intersection, others are characterized by relatively sparse patterns. For example, L43 represents a dense layout where individual workstations form small islands of 6x6 ft and are aligned and oriented according to a perfect orthogonal grid (**figure 6.1-43**). Consequently, the linear representation depicts a dense orthogonal grid with a few clearings due to the core and larger conference rooms. While a similar density is found for bürolandschaft cases L9, L19, L22, L30, L31 and L42, the organic alignment of workstations and clusters of workstations produce grids with a much higher connectivity where lines cross each other at various angles (**figures 6.1-9, 6.1-19, 6.1-22, 6.1-30, 6.1-31** and **6.1-42**).

Second, while some layouts are directionally biased, in the sense that we can clearly identify main circulation lines with very high connectivity running in one direction, others are unbiased in the sense that lines with high connectivity run in different directions. A lower density is found for cases of L3, L14, and L46 which are organized around distinct lines of primary circulation that are both long and connect many secondary ones (**figures 6.1-3, 6.1-14,** and **6.1-46**). However in contrast to dense orthogonal grids and bürolandschaft layouts, these cases show high differentiation of connectivity among individual lines. Lastly, lower densities are found for layouts with large islands of workstation clusters as well as layouts that are predominantly cellular, L4, L16, L39 and L44, hence a few lines and a few connections between the lines (**figures 6.1-4, 6.1-16, 6.1-39** and **6.1-44**).

The linear maps of layouts are quantitatively analyzed with *Spatialist* (Peponis, Wineman at al. 1997) according to their Line Length, Connectivity, Mean Depth and Integration. At a more in-depth level, the analysis has investigated the distribution patterns for measures of Relative Length (the Mean of Line Length equals 1), Connectivity, Mean Depth and Integration for each layout. For this purpose, two kinds of displays have been used: *histograms* and *normal quantile plots* (**figures 6.2-1** to **6.2-50**).

Two main conclusions are drawn from observing patterns of distribution of the four measures across the sample: First, only three patterns of distribution are found: 1) *right-skewed*, where the right tail of histograms is heavier and the normal quantile scatter has a convex shape, L8-Relative Length and L9-(all four measures) (**figures 6.2-8** and **6.2-9**); 2) *normal*, where the distribution approximates a bell curve with symmetrical tails and where the normal quantile plot falls close to a straight line, L15-Relative Length, L15-Integration, L30-Mean Depth and L36-Integration (**figures 6.2-15, 6.2-30** and **6.2-36**); 3) *step-like*, where the histograms show several high points and the quantile plots are stepped or S-shaped, L2-Integration, L6-Mean Depth, L14-Integration and L50-Integration (**figures 6.2-2, 6.2-6, 6.2-14** and **6.2-50**). No cases with left-skewed distributions, hence concave quantile plots have been found[1].

Second, there exists a consistent link between patterns of distribution of Mean Depth and Integration and patterns of distribution of Relative Length and Connectivity. Normal distributions of Relative Length and Connectivity coincide with normal distributions of Mean Depth and Integration. A case in point is L15 and L42 (**figures 6.2-15** and **6.2-42**). Whereas, right-skewed and step-like distributions of Relative Length and Connectivity coincide with step-like distributions of the two other measures, L34, L46 and L50 (**figures 6.2-34, 6.2-46** and **6.2-50**).

The measure of Skewness gauges the sidedness or the symmetry of a distribution. It is based on the third moment about the mean and is computed according to the formula:

$$skewness = \sum z_i^3 \frac{N}{(N-1)(N-2)} \qquad \text{where } z_i^3 = \frac{x_i - \bar{x}}{std(x)} \qquad (6.1)$$

In addition to the mean values of the three original measures, Mean Connectivity, Mean Mean Depth and Mean Integration (Mean Relative Length has been excluded since it equals 1), four more measures have been added to the analysis: Relative Length Skewness, Connectivity Skewness, Mean Depth Skewness and Integration Skewness, (**table 6.2**). It should be noted that

[1] Left-skewed distributions for Relative Length, Connectivity and Integration are exemplified by the theoretical layout where a large number of overlapping axial lines with variable length run in different directions forming a dense core of longer lines and a sparser periphery of shorter lines. However, Mean Depth does not display a left-skewed distribution.

all values of Relative Length Skewness, Connectivity Skewness and Integration Skewness are positive. Only 8 of 50 values of Mean Depth Skewness are negative, while very close to zero, hence reiterating the lack of left-skewed distributions.

The combination of 8 measures into multivariate correlations produces 28 scatterplots, (**table 6.3** and **figure 6.3**). With regards to correlation values, only three scatterplots are worth considering: 1) Lines vs. Mean Mean Depth (r=0.727, p=0.000); 2) Mean Connectivity vs. Integration (r=0.661, p=0.000); 3) Connectivity Skewness vs. Relative Length Skewness (r=0.648, p=0.000). While the first two correlations are obvious, the third shows something specific to office layouts, i.e. layouts in which certain lines are significantly longer causing great skewness of relative length are also much more connected than others, hence, producing greater connectivity skewness. In other words, longer corridors in office layouts are likely to connect more secondary corridors. A possible cause is the modularity of layout resulting from comparable size of islands between axial lines which is produced by workstation clusters and conference rooms in office layouts.

A heuristic examination suggested two fundamental dimensions of variability. First, while some layouts are characterized by dense patterns of intersection, others are characterized by relatively sparse patterns. Second, while some layouts are directionally unbiased, in the sense that we can clearly identify main circulation lines with very high connectivity running in one direction, others are unbiased in the sense that lines with high connectivity run in different directions.

The heuristic intuition corresponds most clearly to a very strong statistical pattern regarding the relationship of Mean Connectivity and Connectivity Skewness. There are no left-skewed connectivity distributions in the sample. High skewness always indicates a small number of lines with a very high number of connections. The scatterplot of Mean Connectivity vs. Connectivity Skewness (**figure 6.4**) despite its poor and non-significant correlation (r=-0.247, p=0.084) stands out due to having a perfect L-shape cloud where no points fall in the upper right quadrant. This finding reinforces the earlier heuristic observation about the existence of three kinds of layouts:

dense and heavily connected layouts, differentiated layouts where a few lines act as organizers and in-between cases which are neither differentiated nor dense.

The sample lends itself to a perfect two-step statistical splitting into three groups. First, it is split into 13 and 37 according to Connectivity, and then the larger sub-sample of 37 is split into 27 and 10 according to Connectivity Skewness (**figure 6.5**). An identical split into groups of 10, 27 and 13 is produced by a two-step splitting starting first with Connectivity Skewness (**figure 6.6**). Thus, the pattern is consistent. The four quadrants are drawn by the vertical line of Mean Connectivity at 4.140 and the horizontal line of Connectivity Skewness at 2.846, according to the value of the statistical splitting (**figure 6.7**). All data points fall in either quadrants 2, 3 or 4, while there are no cases in the quadrant 1.

Accordingly, three types of actual office layouts are distinguished: The first type, termed "biased", represents layouts with low Connectivity and high Connectivity Skewness falling in the top left quadrant. The *fishbone* pattern, whether linear or looped, is proposed to be an ideal type representing the underlying structure of these layouts (**figure 6.8**). The second type, termed "unbiased-sparse", includes layouts with low Connectivity and low Connectivity Skewness composed of elementary and simple systems where a few lines connect to each other without noticeable differentiation; these fall in the bottom left quadrant. The third type, named "unbiased-dense", includes layouts with high Connectivity and low Connectivity Skewness; these fall in the bottom right quadrant and can be dense orthogonal grids or seemingly irregular bürolandschaft layouts. The *grid* evenly extending in both dimensions is proposed as the ideal type representing the underlying structure of these layouts.

The mean values of the 8 measures of Number of Lines, Relative Length Skewness, Mean Connectivity, Connectivity Skewness, Mean Mean Depth, Mean Depth Skewness, Mean Integration and Integration Skewness are compared across three layout types. For each measure, three values are plotted in boxes corresponding to three quadrants and one overall mean for the entire 50 cases, (**figure 6.9**). As expected, biased layouts are distinctly more skewed with regard to both Length and Connectivity than unbiased-sparse and unbiased-dense ones, while unbiased-dense layouts are distinctly more connected with a mean at 4.8. Of particular interest, however, is the behavior of Integration across three types. Among the three types, unbiased-sparse layouts are the least integrated with a mean of 1.442; biased layouts are more integrated with an average of 1.570; unbiased-dense layouts are even more integrated with an average of 1.756. This indicates that there are two ways of increasing integration in actual office layouts: increasing the density of intersections and increasing skewness so that a few lines act as powerful integration spines.

The question arises whether any match exists between the three proposed layout types of biased, unbiased-sparse and unbiased-dense and the three heuristic types of predominantly cellular, predominantly cellular and mixed layouts. The sample is split according to the three heuristic types and each sub-sample is analyzed according to the scatterplot of Mean Connectivity against Connectivity Skewness (**figure 6.10)**. In each of the three split sub-samples, the data points are scattered in all three quadrants, therefore suggesting that no clear link exists between the three types, proposed on the basis of axial map representations, and the three heuristic types, defined according to the predominant cellular or open plan layout type.

The predominantly cellular type represents a peculiarity to the other two types since the majority of cases, 6 of 8, fall in the lower left quadrant of the unbiased-sparse type, while 2 cases fall in the other two quadrants. The layout L14 of Commerzbank falls in the biased type and L34 of Lowe and Partners falls in the unbiased-dense type (**figure 6.10-a**). These two cellular layouts are arranged with shared rooms in one or two sides of long primary circulations (**figures 6.1-14** and **6.1-34**). According to the conventions for drawing the axial maps, explained earlier, axial lines are drawn inside shared spaces, whereas they are not drawn inside individual spaces. Depending from a convention where axial lines are not drawn inside shared rooms, these two layouts will fall in the lower left quadrant due to lacking the fishbone lines crossing the main spines. Therefore, layouts of the predominantly cellular type are likely to be of the unbiased-sparse type, and arguably, it is possible to suggest that depending on the rules of drawing axial maps, the predominantly cellular type coincides with the unbiased-sparse layout.

The mean values of the 8 measures are compared across the three heuristic layout types of predominantly cellular, predominantly open plan and mixed. For each measure, three mean values are plotted in boxes corresponding to the three types and one overall mean for the entire sample, (**figure 6.11**). The ranking order of means for the 8 measures among these types is compared to the ranking order of the means for the 8 measures among the proposed types of biased, unbiased-sparse and unbiased-dense (**table 6.4**). Except Relative Length Skewness, the other 7 measures display a perfect match in the ranking order between the predominantly cellular type and the unbiased-sparse type, shown with boxes in **table 6.4,** reinforcing the earlier observation that the two types coincide.

Therefore, it is concluded that no match exist between the two heuristic types of predominantly open plan and mixed, in one hand, and the two proposed types of biased and unbiased-dense, in the other. Meanwhile, there is strong evidence to suggest the possibility that the proposed unbiased-sparse type coincides with the predominantly cellular office layouts.

6.2 The Interaction of Floorplate Shape and Layout Connectivity and Integration

This section explores the interaction between actual duos of layouts and floorplates from the viewpoint of the effect of floorplate shape on Integration. The findings of this section are intended to suggest hypothetical directions for unraveling this relationship without attempting to prove the existence of significant patterns. First, as it was stated at the very outset of the thesis, actual office layouts are affected by a number of requirements arising from the spatial needs of the occupant organizations and by the ability of designers to negotiate the constraints imposed by the structure of the building shell, including the floorplate shape. Each duo of layout and shape constitutes a unique case involving complex relationships of floorplate characteristics, managerial models underlying the brief, designer's artistic preferences as well as constraints and possibilities offered by the furniture systems. Hence, the task of disentangling the effect of floorplate shape out of a variety of these influencing factors cannot be achieved by investigating duos, even if in large numbers. Second, while searching for different patterns across three layout types, the significance of any statistical finding will be greatly reduced as the number of data points reduces from 50 to 10, 13 and 27. For these two reasons, the analysis of actual duos of floorplate shapes and layouts has been given the character of a pilot exercise aimed at suggesting hypothetical propositions.

The two measures of floorplate shape, Relative Grid Distance and Convex Fragmentation, are plotted against 8 measures of layouts: Number of Lines, Skewness of Line Length, Connectivity, Connectivity Skewness, Mean Depth, Mean Depth Skewness, Integration and Integration Skewness. The plots suggest a loose but linear pattern of co-variation so that linear correlation coefficients are computed, as shown in **table 6.5** and **figure 6.12**. There are significant correlations between Relative Grid Distance and Skewness of Line Length as well as Connectivity. These show that less compact floorplates are associated with layouts which have a few dominant circulation lines and a lesser density of circulation intersections. The results meet intuitive expectations. However, there are no significant correlations with Integration. At the aggregate level of analysis shape affects the arrangement of circulation but does not appear to affects its syntactic structure.

Correlations are also computed for the three sub-samples separately as shown in **table 6.6** and **figure 6.13**: the 10 biased layouts, the 27 unbiased sparse layouts and the 13 unbiased dense layouts. None of the correlations between Connectivity, Connectivity Skewness and Integration are significant, due, at least in part, to the small sample sizes. However, an interesting difference emerges regarding the three types of layouts. Correlations between Convex Fragmentation and Integration are much smaller for the biased and unbiased sparse layouts than they are for the unbiased dense layouts. The same applies to the correlations between Relative Grid Distance and Connectivity. Thus, it would seem that the tendency for greater Relative Grid Distance and Convex Fragmentation to be associated with less Connectivity and less Integration respectively is stronger for unbiased dense layouts.

Two theoretical considerations arise. The first is the necessity to approach the interaction between floorplate shape and the Integration of layouts more theoretically. Indeed, the insignificant correlations reported above could indicate two different things: either that floorplate shape does not affect Integration, or that the effects are weak by comparison to other variables ranging from the ability of designers to work within a set of shape-constraints, to the diversity of organizational requirements regarding layout. Experimentation with hypothetical but consistently developed layouts would help clarify this. The second consideration is the possibility that different layout types interact differently with floorplate shapes.

6.3 Two Ideal Layouts of Grids and Fishbones

The challenges identified in the previous section are addressed as follows. First, in order to better control comparisons between floorplates, two standardized ideal layouts are chosen: the regular rectangular *grid* and the *fishbone*. These, as it was shown, represent alternative ways in which layout Integration can increase; they also represent alternative layout types (**figure 6.8**). The two layouts are also more structured than unbiased sparse layouts either by having a few organizing lines that connect most others, or being denser where order is achieved by an increased and almost constant connectivity. These layouts represent predominantly open plan and mixed layouts, rather than predominantly cellular layouts. Second, these ideal layouts are systematically inserted in two sets of floorplates: A set of simple hypothetical floorplates and the sample of fifty actual floorplates. This approach allows us to explore whether shapes exercise underlying constraints upon internal layouts, differences in design skill and programmatic requirements not withstanding.

The grain for both layouts is based on a cluster of 4 workstations of about 8x8 ft, a circulation width of 4 ft, whereby both may be slightly adjusted to fit the mullion grid or the depth from core to perimeter. Hypothetical layouts will be cell farms, i.e. individual cubicles attached to rectangular circulation grids.

The *grid* hypothetical layout is based on highest density and the least possible differentiation. Cubicles are clustered in sets of four, so that two sides of each cubicle are adjacent to a circulation space and the other two sides to other cubicles, (**figure 6.14**). This is too generous an arrangement from the point of view of circulation but it has the advantage that the pattern is the same in both directions.

The *fishbone* hypothetical layout is an ideal case of biased layouts whereby single primary circulation connects secondary lines perpendicular to it. In this layout, back-to-back pairs of cubicles will be grouped in longer strings, four or more in a row (**figure 6.15**). This arrangement is more economical from the point of view of circulation. In this case, the density of cubicles per circulation line is higher in one direction, and the density of intersections between circulation lines is higher in the other. In the fishbone, primary lines of circulation are parallel with the longest axis of each sub-area in the floorplate and, in the case of central core start form the core.

6.4 Conclusions

This chapter proposed a typology of office layouts based on degrees of bias and density of their linear map representations. The methodology involved three steps: analyzing the sample of actual office layouts, proposing a typological classification, and searching for consistent patterns of dependency of layout measures from features of floorplate shape across the proposed types. The sample of analysis included fifty layouts representing a wide variety from best practice in architecture and space planning spanning five decades.

The chosen layouts represent a variety of predominantly open plan, predominantly cellular and mixed layouts. The heuristic examination distinguished two fundamental dimensions of variability among layouts: density and bias. While some layouts are characterized by dense patterns of intersections, others have relatively sparse patterns. While some layouts are directionally biased, in the sense that a few circulation lines connect most others and run in one direction, some layouts are unbiased in the sense that lines with comparably equal connectivity run in different directions.

The analysis of linear representations of these layouts reinforced the heuristic intuition by demonstrating a strong statistical pattern regarding the relationship between Mean Connectivity and Connectivity Skewness. Accordingly, three types of office layout were proposed: The first type, termed *biased* represents layouts with low Connectivity and high Connectivity Skewness; The second type, termed *unbiased-sparse*, includes layouts with low Connectivity and low Connectivity Skewness composed of elementary and simple systems; The third type, termed *unbiased-dense*, includes layouts with high Connectivity and low Connectivity Skewness representing dense orthogonal grids or seemingly irregular bürolandschaft layouts.

Among the three types, unbiased-sparse layouts are the least integrated, biased layouts are more integrated while unbiased-dense layouts are even more integrated, indicating that there are two ways of increasing integration in actual office layouts: increasing the density of intersections and increasing skewness or bias so that a few lines act as powerful integration spines.

Correlations between floorplate shape measures and layout measures were computed for the entire sample of fifty examples and the three sub-samples of the proposed layout types. At the aggregate level of analysis shape affects the arrangement of circulation but does not appear to affects its syntactic structure. Due to the smaller size of the sub-samples, no significant correlations were found between shape measures and layout measures, despite stronger correlations between shape and layout for unbiased dense layouts.

In conclusion, it is suggested that it is the necessary to approach the interaction between floorplate shape and the Integration of layouts from a theoretical perspective due to the insignificant correlations between measures of shape and layout. In order to better control comparisons between floorplates, two standardized ideal layouts are chosen: the *fishbone* and the regular rectangular *grid*, representing alternative ways in which layout Integration can increase as well as alternative layout types. The comparison among the three heuristic types and the three proposed types suggested that the predominantly cellular type matches the unbiased-sparse type. Therefore, the proposed ideal fishbone and grid layouts will primarily address conditions of predominantly open plan and mixed layouts. The next chapter will develop experimentations with the two hypothetical layouts in order to help clarify whether, in one hand, floorplate shapes affect layout integration, and in the other hand, their effect varies according to different layout types. For this purpose, in the next chapter the ideal layouts are systematically inserted in two sets of floorplates: A set of simple hypothetical floorplates and the sample of fifty actual floorplates. This approach allows exploring whether shapes exercise underlying constraints upon internal layouts by excluding differences in design skill and programmatic requirements.

Table 6.1: Classification of the sample of actual layouts according to the predominant type of open plan and cellular configurations.

	name	net floor area sq ft	cellular % of floor area	open plan % of floor area	predominant layout type
1	3com Corporation	38,700	0	32.6	open plan
2	Andersen (after move)	31,200	12.9	29.5	mixed
3	Andersen (before move)	14,100	43.6	28.5	mixed
4	Allen & Overy	8,300	41.3	10.6	cellular
5	Arthur Andersen	12,700	0	35.6	open plan
6	Apicorp	39,100	30.5	5.5	cellular
7	Apple Computer Inc.	48,900	5.2	33.3	open plan
8	Andersen Consulting	4,450	18.7	13.2	mixed
9	Buch und Ton	24,300	0	48.5	open plan
10	Chase Manhattan Bank	38,800	9.7	24.2	mixed
11	Chiat/Day Advertising	18,700	0	30.9	open plan
12	TBWA Chiat/Day	21,500	3.0	17.3	open plan
13	Citicorp	22,800	20.8	33.8	mixed
14	Commerzbank AG	12,300	67.3	0.5	cellular
15	Data-Firmengruppe	12,900	31.3	31.5	mixed
16	Davis Polk & Wardwell	24,500	44.8	12.2	mixed
17	DEGW London Office	14,350	0	21.0	open plan
18	Discovery Channel Latin Am.	21,450	23.5	17.3	mixed
19	DuPont	10,200	0	42.7	open plan
20	The Equitable	18,500	10.0	43.3	open plan
21	Ford Foundation	11,900	53.2	10.2	cellular
22	Ford Motor Co.	23,350	0	59.6	open plan
23	f/X Networks	16,550	28.1	21.5	mixed
24	Greenberg Traurig	25,800	43.8	9.5	cellular
25	Hoffmann - La Roche	30,000	1.6	32.3	open plan
26	IBM Regional Headquarters	86,500	0	27.6	open plan
27	IBM (UK) Limited	35,000	19.0	18.0	mixed
28	IBM Australia	12,300	31.7	2.3	cellular
29	Interpolis	4,850	28.8	16.8	mixed
30	Direct. of Telecom., MPBW	14,400	0	58.3	open plan
31	Eastman Kodak	28,300	0	67.0	open plan
32	Lend Lease Interiors	8,450	4.5	42.4	open plan
33	Leo A Daly	21,050	0	28.4	open plan
34	Lowe & Partners/SMS	20,900	49.5	5.5	cellular
35	McDonald’s	15,450	6.5	25.5	open plan
36	McDonald’s Italia	21,500	8.2	19.2	mixed
37	MGIC	20,150	27.6	13.6	mixed
38	Nickelodeon	24,300	8.5	38.5	open plan
39	Olivetti A	5,650	7.9	68.7	open plan
40	Olivetti B	5,650	4.1	62.9	open plan
41	Olivetti C	5,650	4.7	73.8	open plan
42	Orenstein-Koppel	17,500	0	38.8	open plan
43	Sears 40	44,100	17.1	32.7	mixed
44	Sears 70	23,100	39.7	8.9	cellular
45	Steelcase Inc.	20,200	0	38.9	open plan
46	British Telec., 5 Longwalk	54,400	4.8	51.4	open plan
47	British Telec., The Square	16,450	5.7	42.5	open plan
48	Vitra International AG	10,100	22.7	31.7	mixed
49	Weyerhaeuser Company	41,750	0	45.0	open plan
50	WMA Consulting Engineers	17,300	12.1	36.6	mixed

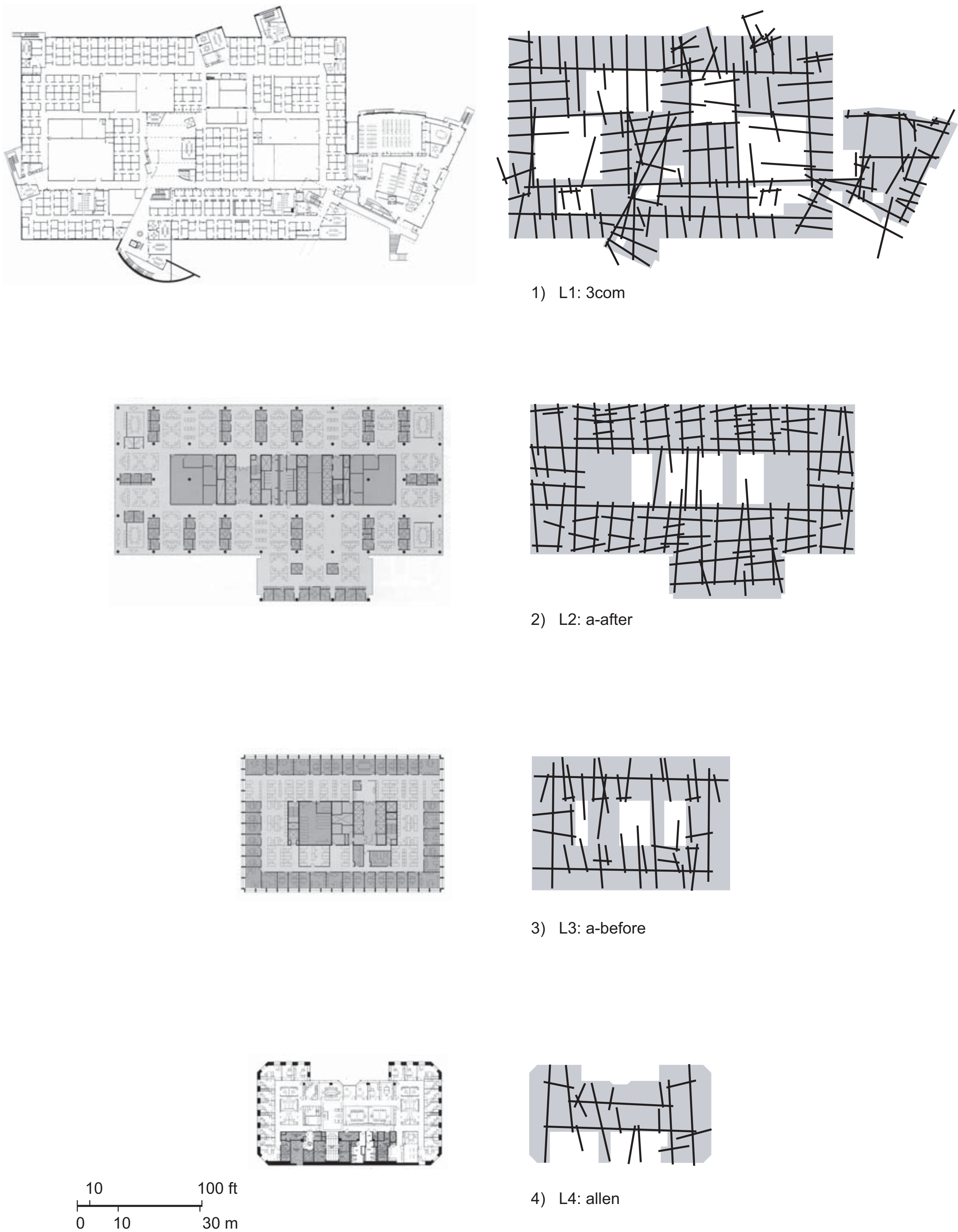
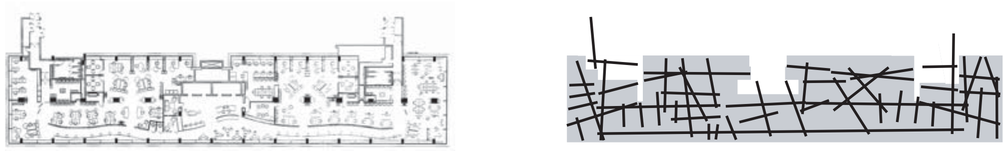
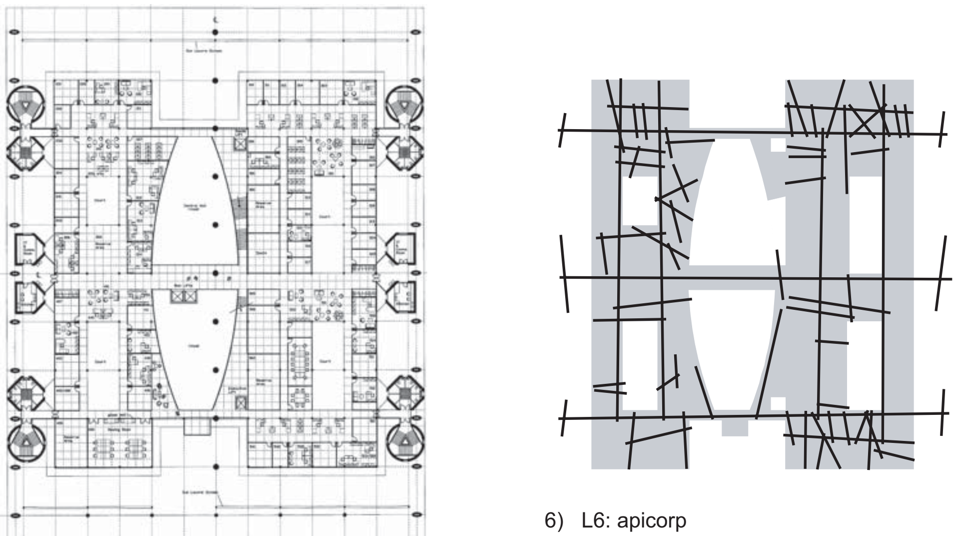


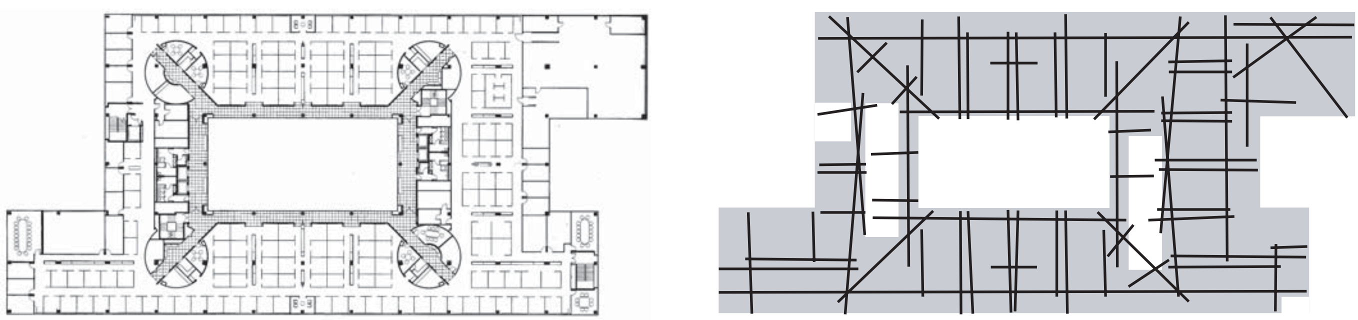
Figure 6.1: Linear map representations of actual office layouts (L1 to L4).



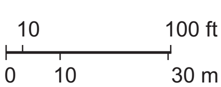
5) L5: a-london



6) L6: apicorp

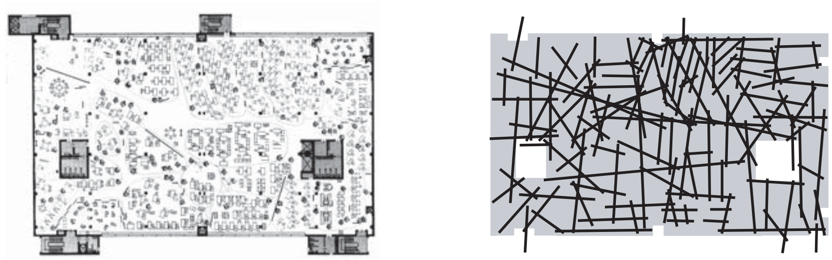


7) L7: apple

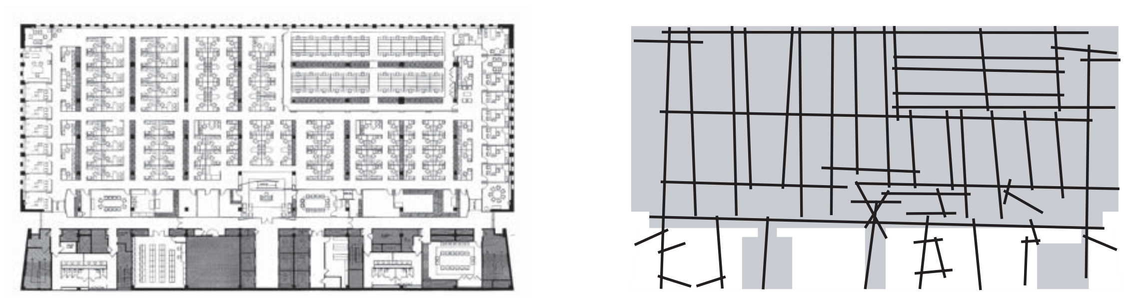


8) L8: a-prague

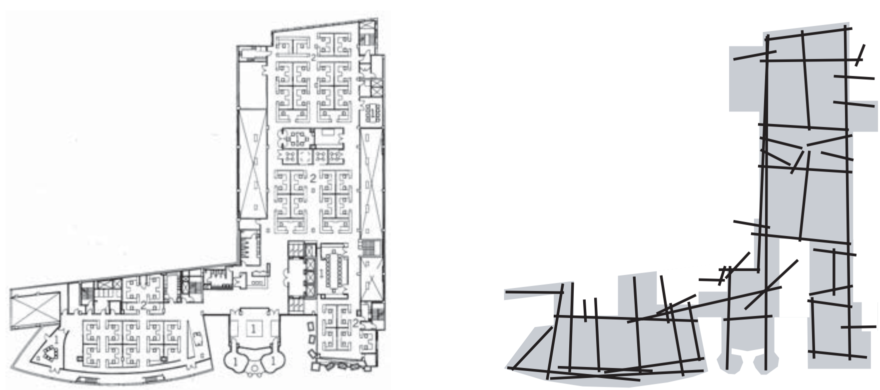
Figure 6.1 continued: (L5 to L8).



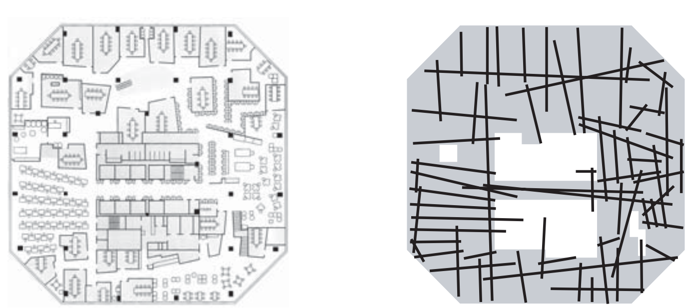
9) L9: buch



10) L10: chase

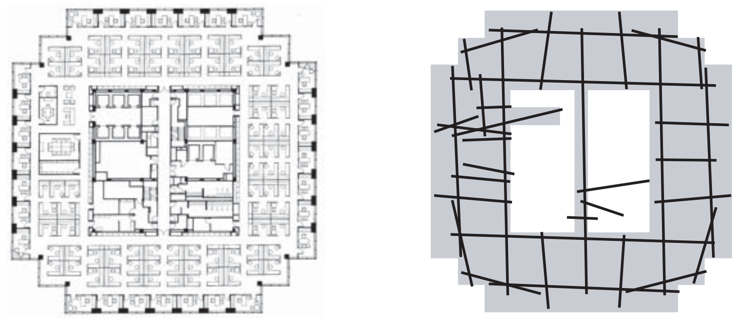


11) L11: chiat-ca

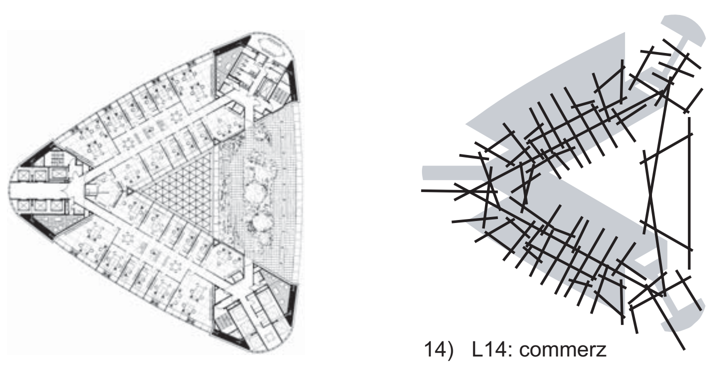


12) L12: chiat-ny

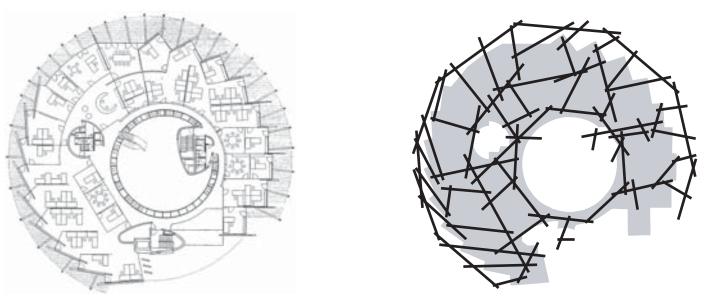
Figure 6.1 continued: (L9 to L12).



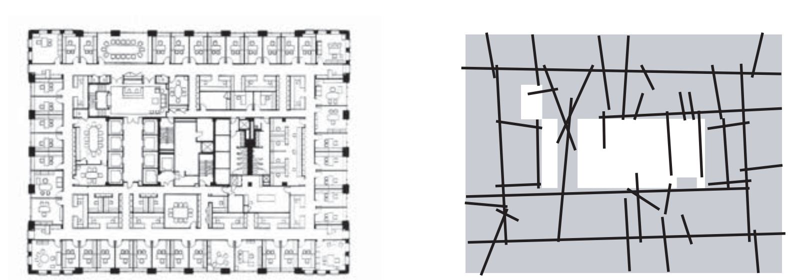
13) L13: citicorp



14) L14: commerz

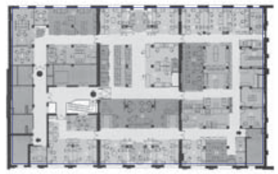


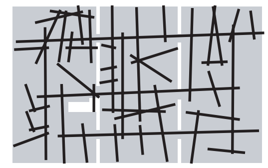
15) L15: datapec



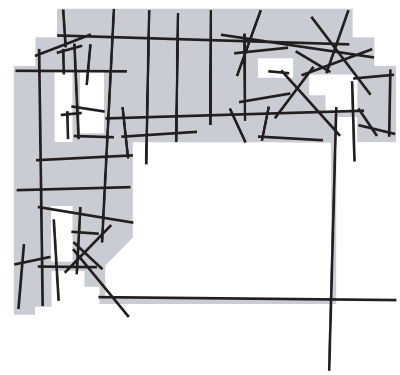
16) L16: davis

Figure 6.1 continued: (L13 to L16).

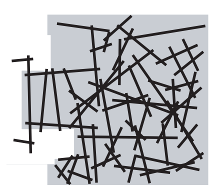




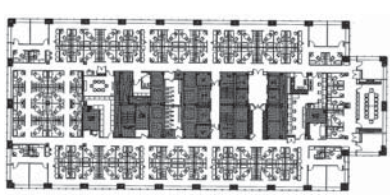
17) L17: degw

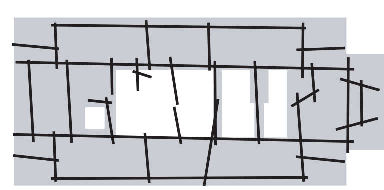


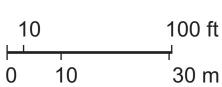
18) L18: discovery



19) L19: dupont

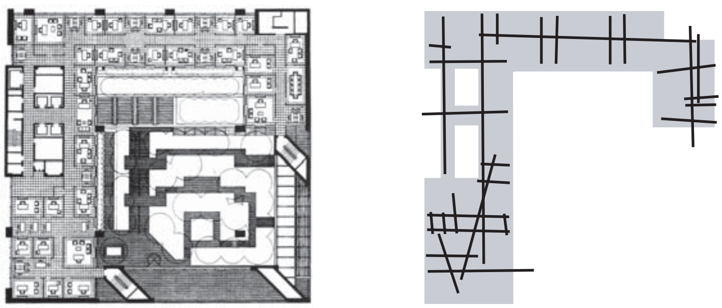




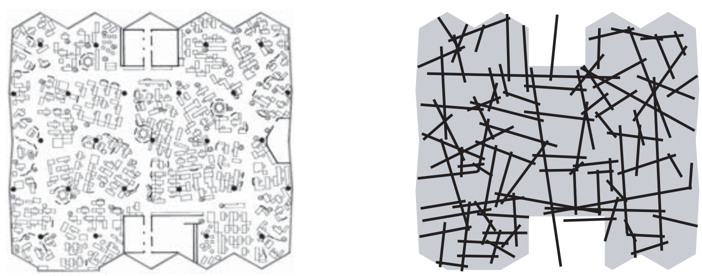


20) L20: equitable

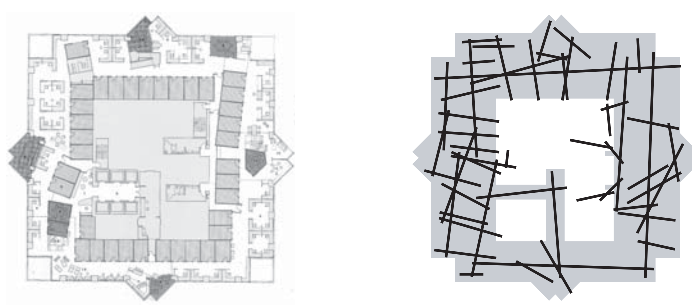
Figure 6.1 continued: (L17 to L20).



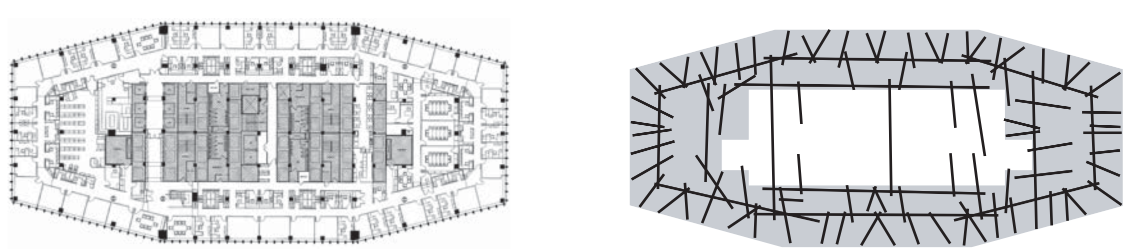
21) L21: ford-f

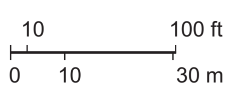


22) L22: ford-m



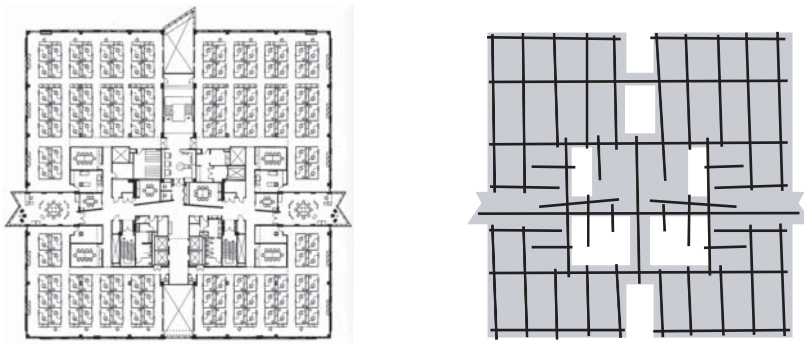
23) L23: fx



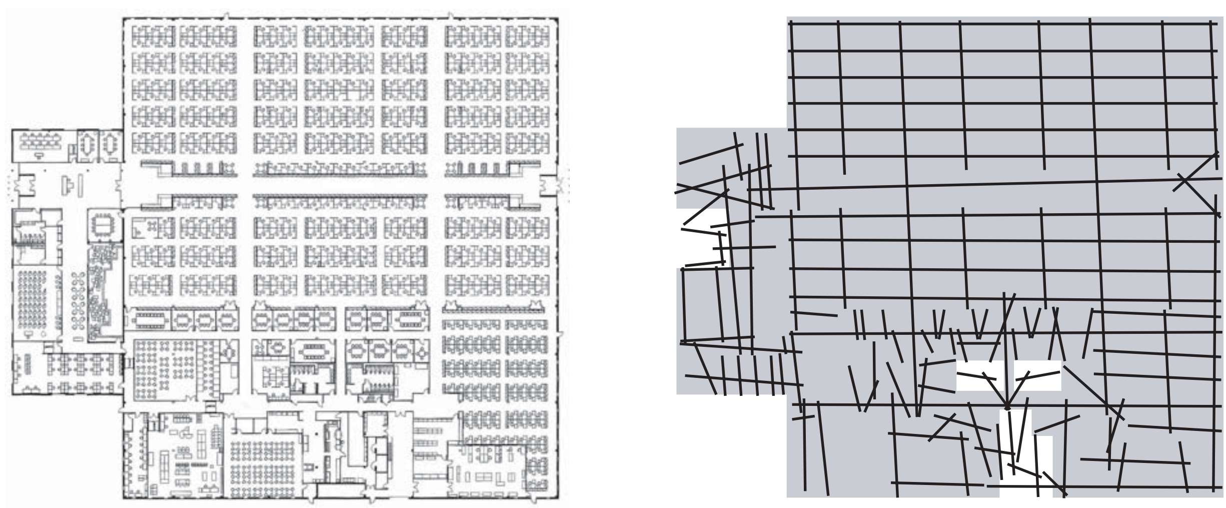


24) L24: greenberg

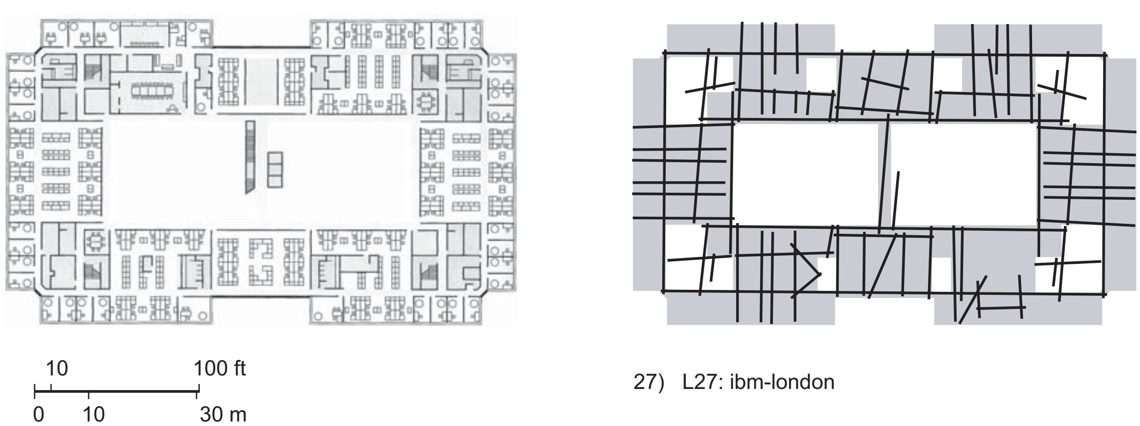
Figure 6.1 continued: (L21 to L24).



25) L25: hoffmann

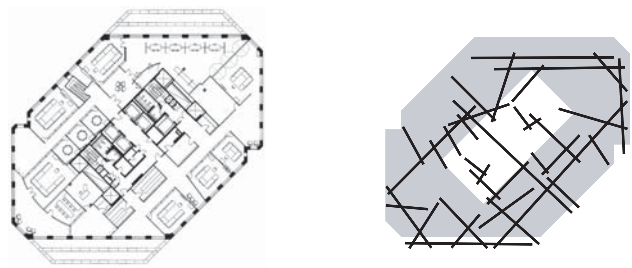


26) L26: ibm-cranford



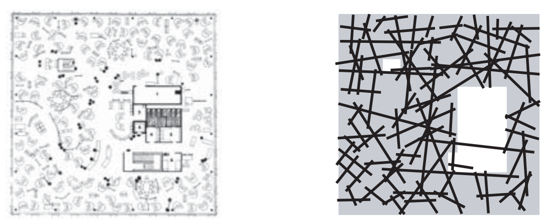
27) L27: ibm-london

Figure 6.1 continued: (L25 to L27).

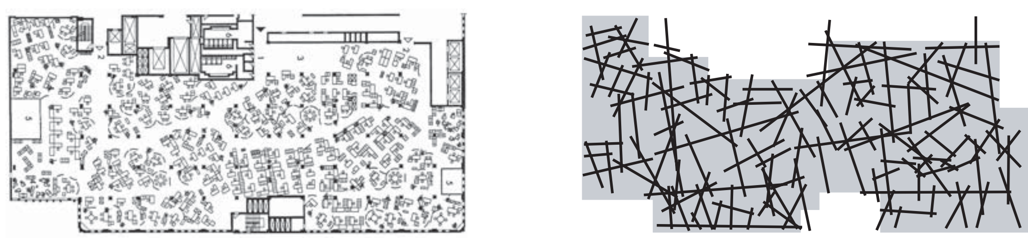


28) L28: ibm-melbourne

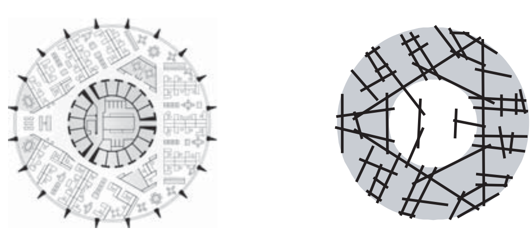
29) L29: interpolis

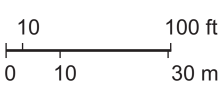


30) L30: kew



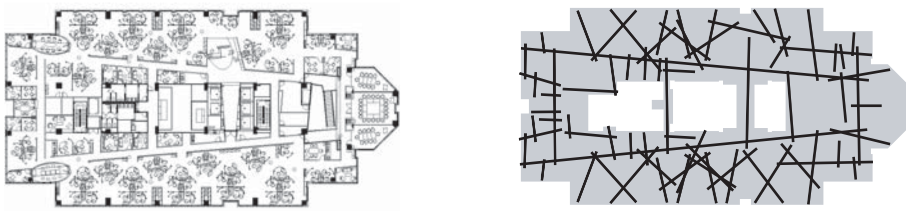
31) L31: kodak



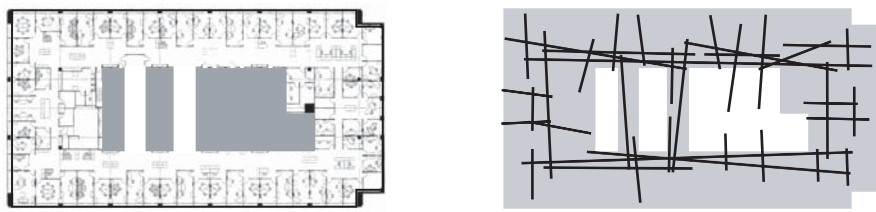


32) L32: lend

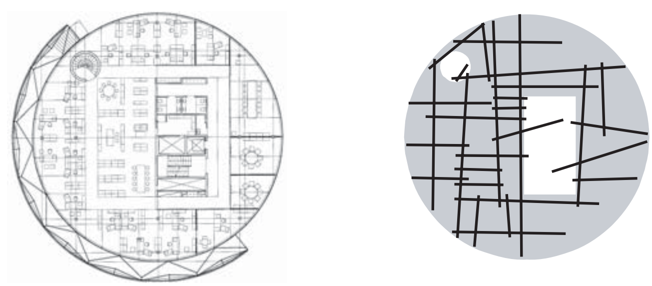
Figure 6.1 continued: (L28 to L32).



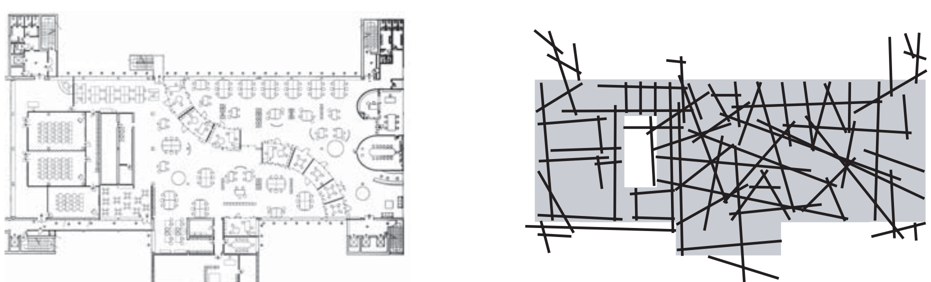
33) L33: leo



34) L34: lowe



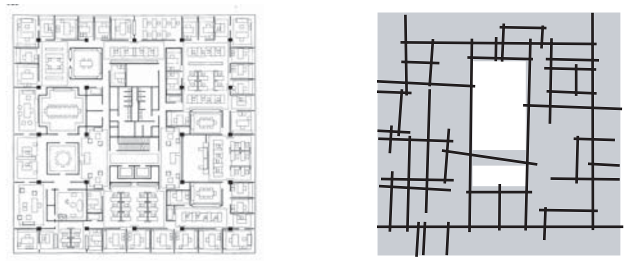
35) L35: mc-helsinki



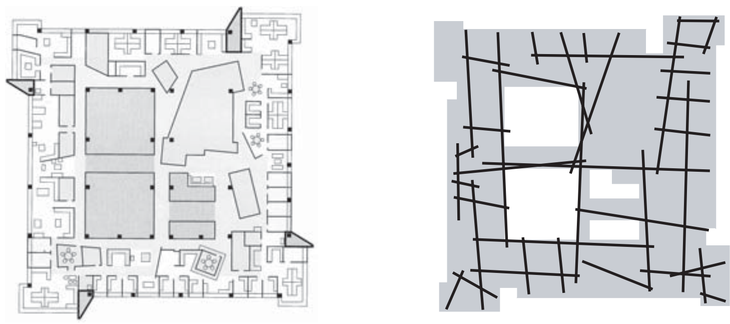
36) L36: mc-milan

10 100 ft
0 10 30 m

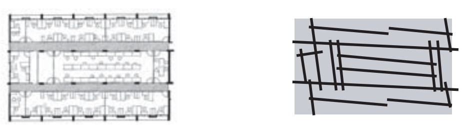
Figure 6.1 continued: (L33 to L36).



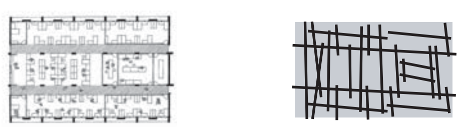
37) L37: mgic



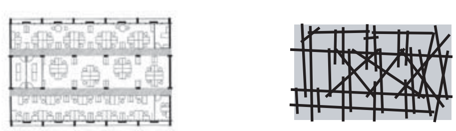
38) L38: nickelodeon



39) L39: olivetti-a

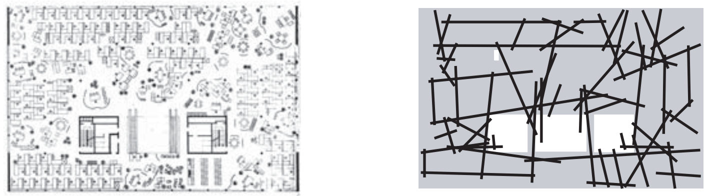


40) L40: olivetti-b

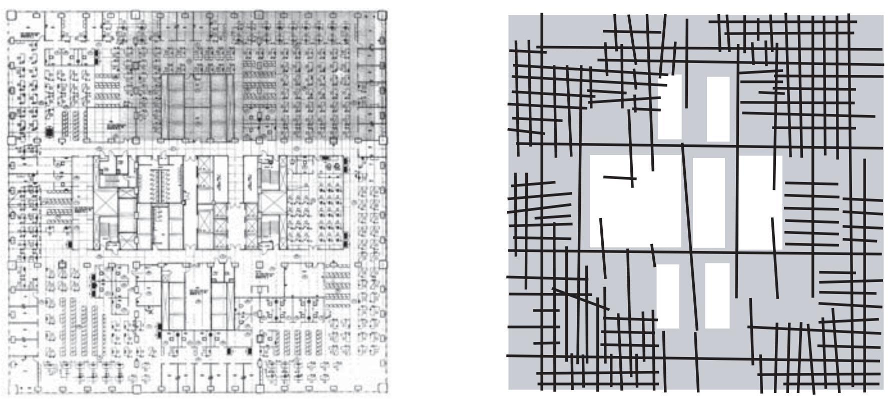


41) L41: olivetti-c

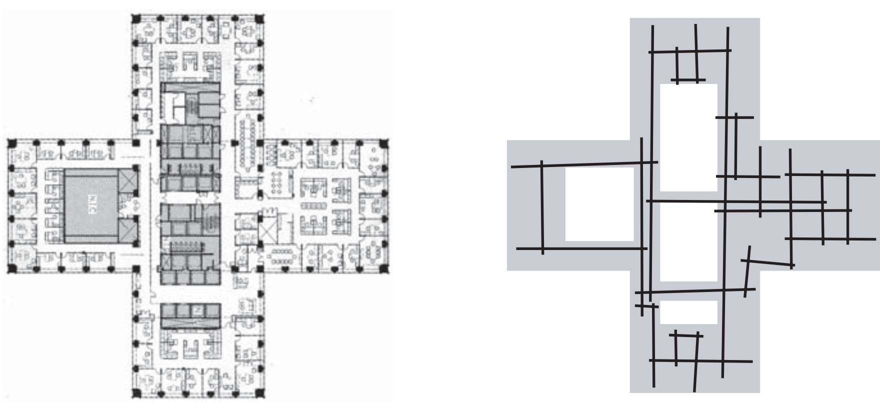
Figure 6.1 continued: (L37 to L41).



42) L42: orenstein

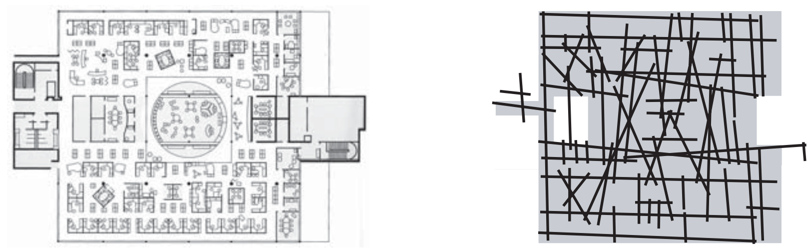


43) L43: sears-40

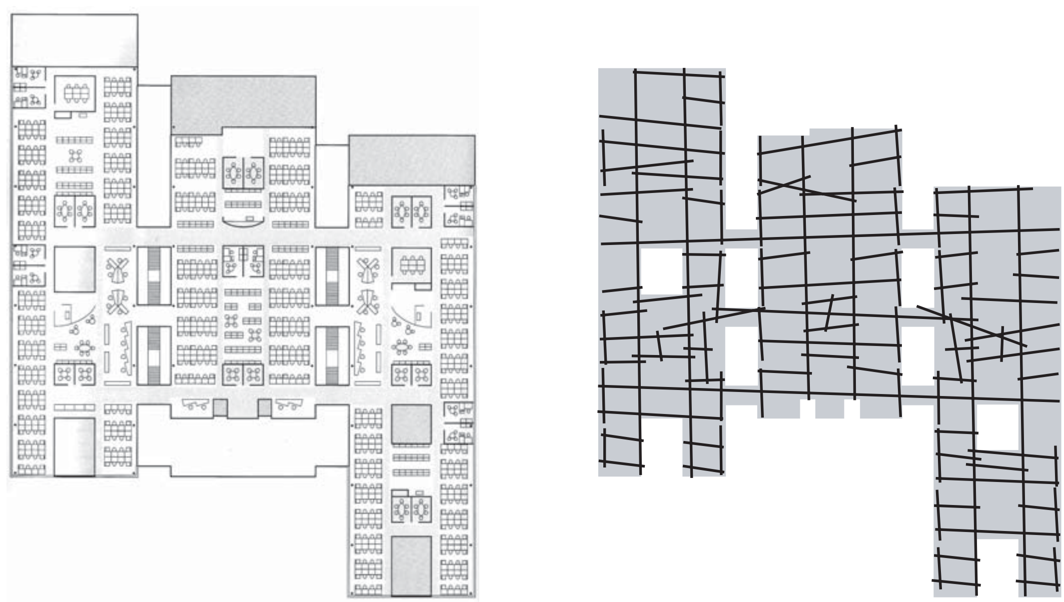


44) L44: sears-70

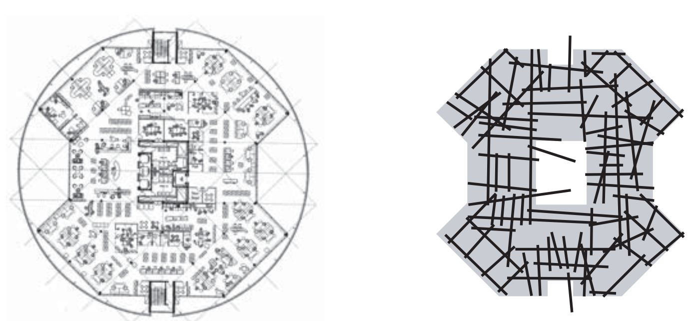
Figure 6.1 continued: (L42 to L44).



45) L45: steelcase



46) L46: stockley-5



47) L47: stockley-sq

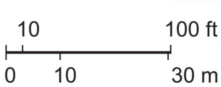
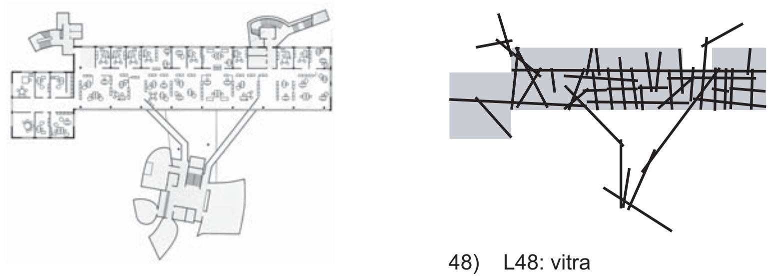
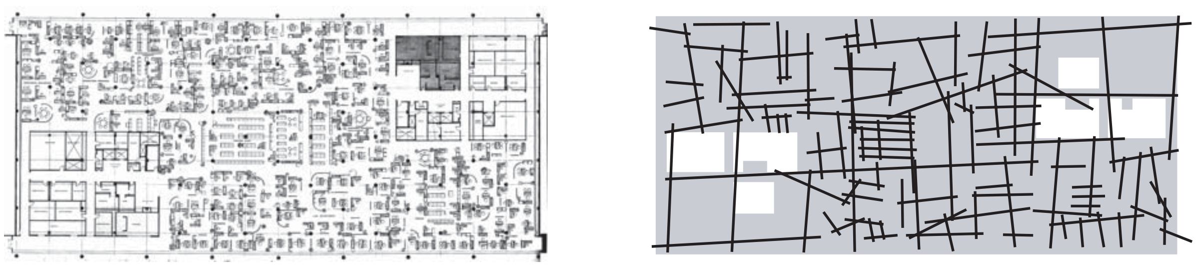


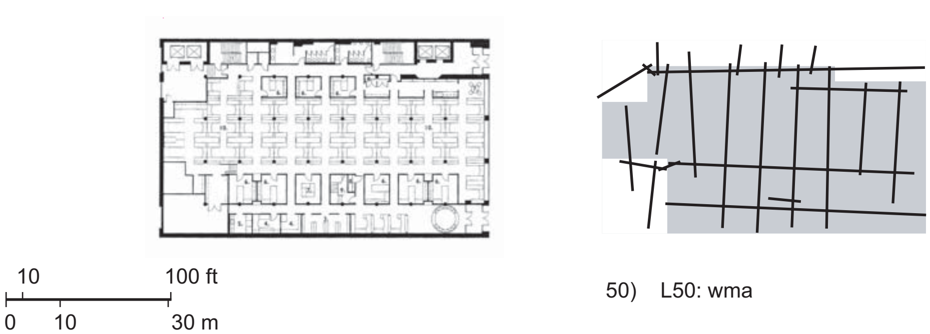
Figure 6.1 continued: (L45 to L47).



48) L48: vitra



49) L49: weyer



50) L50: wma

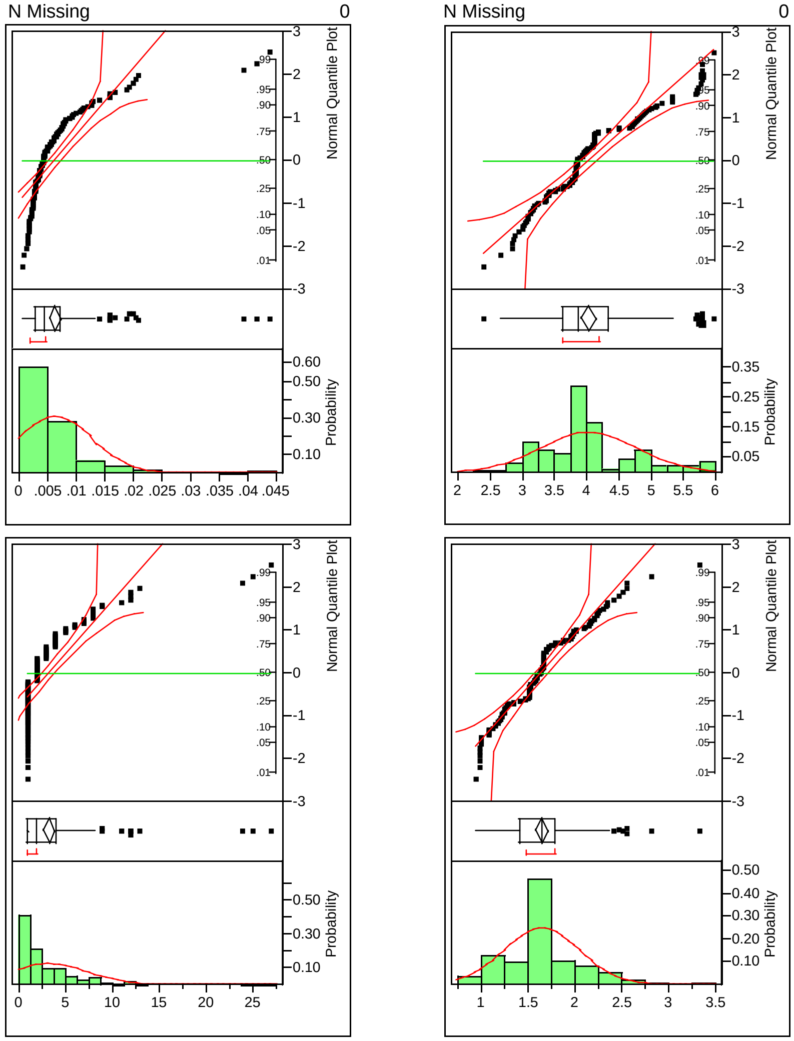
Figure 6.1 continued: (L48 to L50).

Relative Length

Mean	0.0064516
Std Dev	0.0064624
Std Err Mean	0.0005191
upper 95% Mean	0.007477
lower 95% Mean	0.0054262
N	155
Sum Wgt	155
Sum	1
Variance	0.0000418
Skewness	3.5809732
Kurtosis	16.034898
CV	100.1671
N Missing	0

Mean Depth

Mean	4.0435226
Std Dev	0.7469425
Std Err Mean	0.0599959
upper 95% Mean	4.1620437
lower 95% Mean	3.9250015
N	155
Sum Wgt	155
Sum	626.746
Variance	0.5579231
Skewness	0.6866819
Kurtosis	0.2069657
CV	18.472569
N Missing	0



Connectivity

Mean	3.2774194
Std Dev	4.0556766
Std Err Mean	0.3257598
upper 95% Mean	3.9209539
lower 95% Mean	2.6338848
N	155
Sum Wgt	155
Sum	508
Variance	16.448513
Skewness	3.5844976
Kurtosis	15.944594
CV	123.74604
N Missing	0

Integration

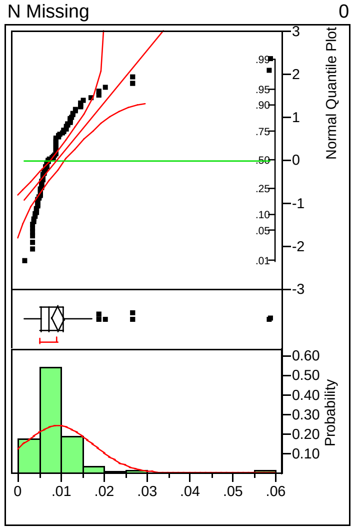
Mean	1.6530387
Std Dev	0.4057089
Std Err Mean	0.0325873
upper 95% Mean	1.7174146
lower 95% Mean	1.5886628
N	155
Sum Wgt	155
Sum	256.221
Variance	0.1645997
Skewness	0.7976186
Kurtosis	1.4332981
CV	24.54322
N Missing	0

1) L1: 3com

Figure 6.2: Distribution patterns of four layout measures (L1).

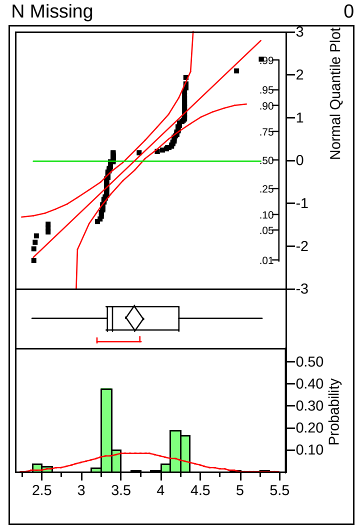
Relative Length

Mean	0.009434
Std Dev	0.0082089
Std Err Mean	0.0007973
upper 95% Mean	0.0110149
lower 95% Mean	0.007853
N	106
Sum Wgt	106
Sum	1
Variance	0.0000674
Skewness	4.3897159
Kurtosis	23.743699
CV	87.014766
N Missing	0

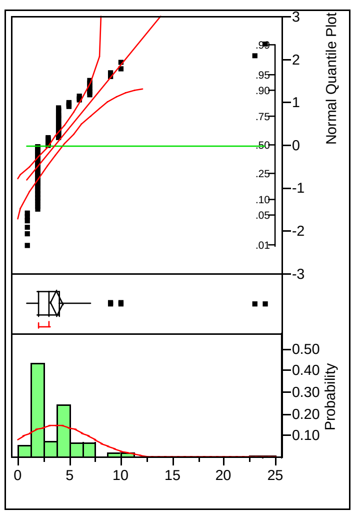


Mean Depth

Mean	3.6801509
Std Dev	0.5666897
Std Err Mean	0.0550418
upper 95% Mean	3.7892886
lower 95% Mean	3.5710133
N	106
Sum Wgt	106
Sum	390.096
Variance	0.3211373
Skewness	-0.022607
Kurtosis	-0.273741
CV	15.398546
N Missing	0

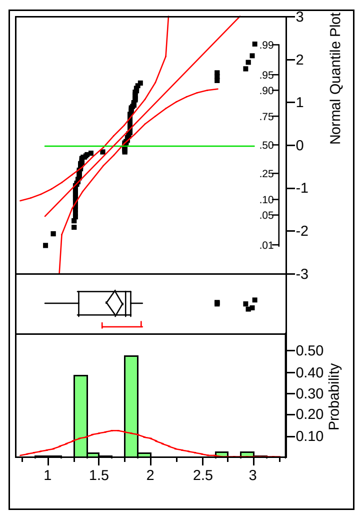


Connectivity



Mean	3.754717
Std Dev	3.3829019
Std Err Mean	0.3285765
upper 95% Mean	4.4062234
lower 95% Mean	3.1032105
N	106
Sum Wgt	106
Sum	398
Variance	11.444025
Skewness	4.0382826
Kurtosis	20.887558
CV	90.097387
N Missing	0

Integration



Mean	1.6548491
Std Dev	0.4055592
Std Err Mean	0.0393914
upper 95% Mean	1.7329549
lower 95% Mean	1.5767432
N	106
Sum Wgt	106
Sum	175.414
Variance	0.1644782
Skewness	1.4601555
Kurtosis	2.9256814
CV	24.50732
N Missing	0

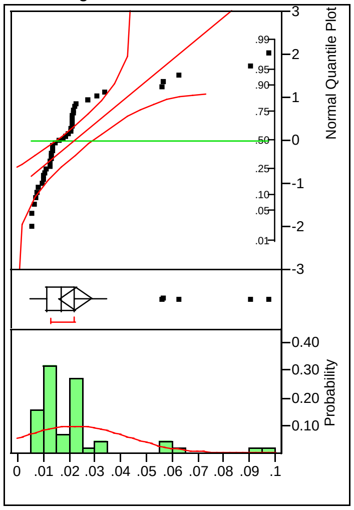
2) L2: a-after

Figure 6.2 continued: (L2).

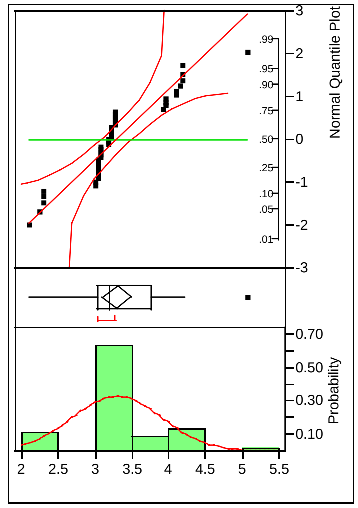
Relative Length	
Mean	0.0227273
Std Dev	0.0202272
Std Err Mean	0.0030494
upper 95% Mean	0.0288769
lower 95% Mean	0.0165776
N	44
Sum Wgt	44
Sum	1
Variance	0.0004091
Skewness	2.4768025
Kurtosis	6.1888166
CV	88.999836
N Missing	0

Mean Depth	
Mean	3.3066136
Std Dev	0.6080809
Std Err Mean	0.0916717
upper 95% Mean	3.4914871
lower 95% Mean	3.1217401
N	44
Sum Wgt	44
Sum	145.491
Variance	0.3697624
Skewness	0.5012948
Kurtosis	0.8204492
CV	18.389839
N Missing	0

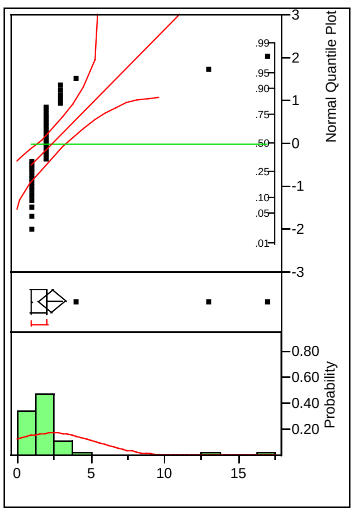
Relative Length



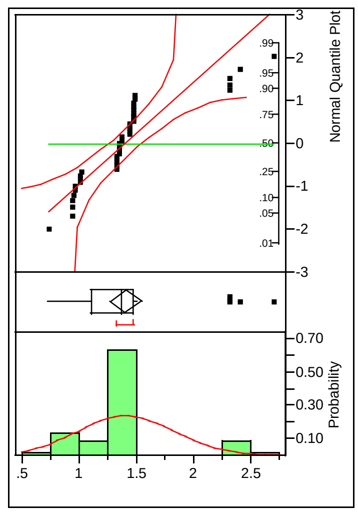
Mean Depth



Connectivity



Integration



Connectivity	
Mean	2.4090909
Std Dev	2.9040323
Std Err Mean	0.4377993
upper 95% Mean	3.2919974
lower 95% Mean	1.5261844
N	44
Sum Wgt	44
Sum	106
Variance	8.4334038
Skewness	4.2337524
Kurtosis	18.574851
CV	120.54474
N Missing	0

Integration	
Mean	1.4135682
Std Dev	0.4213499
Std Err Mean	0.0635209
upper 95% Mean	1.5416703
lower 95% Mean	1.2854661
N	44
Sum Wgt	44
Sum	62.197
Variance	0.1775357
Skewness	1.4215484
Kurtosis	2.3106284
CV	29.80754
N Missing	0

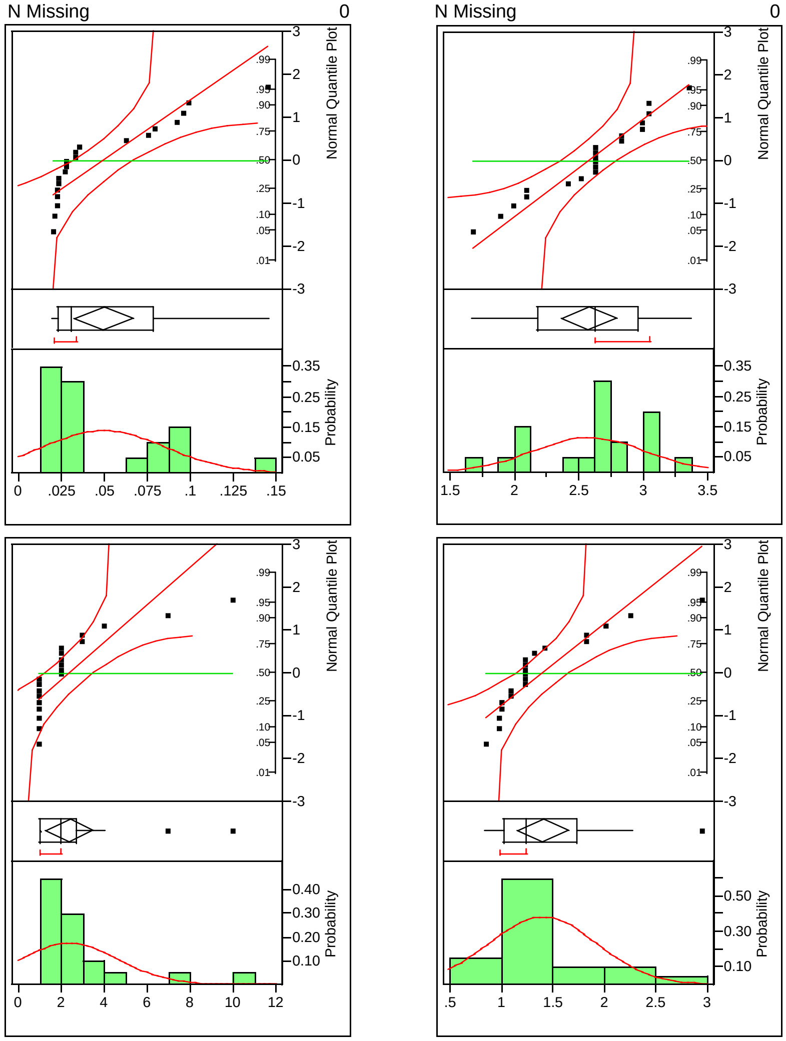
3) L3: a-before

Figure 6.2 continued: (L3).

Mean	0.05	Mean	2.5843
Std Dev	0.0360463	Std Dev	0.439032
Std Err Mean	0.0080602	Std Err Mean	0.0981705
upper 95% Mean	0.0668702	upper 95% Mean	2.7897733
lower 95% Mean	0.0331298	lower 95% Mean	2.3788267
N	20	N	20
Sum Wgt	20	Sum Wgt	20
Sum	1	Sum	51.686
Variance	0.0012993	Variance	0.1927491
Skewness	1.2908512	Skewness	-0.425471
Kurtosis	0.8875666	Kurtosis	-0.335053
CV	72.092584	CV	16.988429
N Missing	0	N Missing	0

Relative Length

Mean Depth



Connectivity

Integration

Mean	2.4	Mean	1.40885
Std Dev	2.3033157	Std Dev	0.5242536
Std Err Mean	0.515037	Std Err Mean	0.1172267
upper 95% Mean	3.4779849	upper 95% Mean	1.6542082
lower 95% Mean	1.3220151	lower 95% Mean	1.1634918
N	20	N	20
Sum Wgt	20	Sum Wgt	20
Sum	48	Sum	28.177
Variance	5.3052632	Variance	0.2748418
Skewness	2.4682614	Skewness	1.713144
Kurtosis	6.2793729	Kurtosis	2.9428979
CV	95.971487	CV	37.211455
N Missing	0	N Missing	0

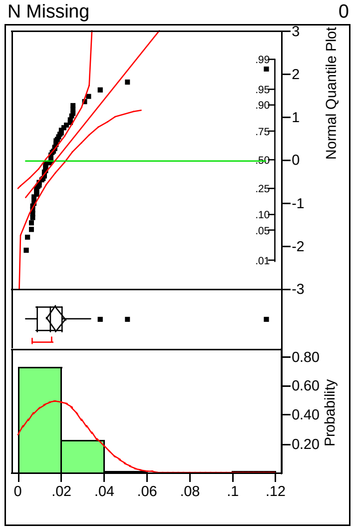
4) L4: allen

Figure 6.2 continued: (L4).

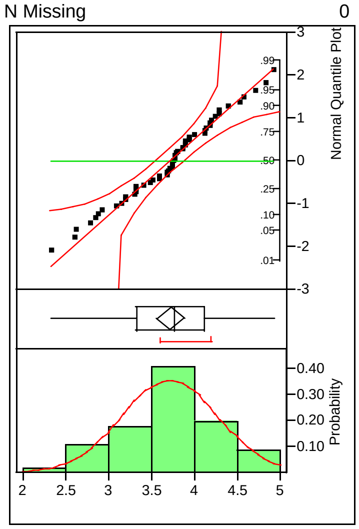
Relative Length	
Mean	0.0178571
Std Dev	0.0160722
Std Err Mean	0.0021477
upper 95% Mean	0.0221613
lower 95% Mean	0.013553
N	56
Sum Wgt	56
Sum	1
Variance	0.0002583
Skewness	4.470758
Kurtosis	25.817647
CV	90.004171
N Missing	0

Mean Depth	
Mean	3.72525
Std Dev	0.5617111
Std Err Mean	0.0750618
upper 95% Mean	3.8756772
lower 95% Mean	3.5748228
N	56
Sum Wgt	56
Sum	208.614
Variance	0.3155194
Skewness	-0.231683
Kurtosis	0.0071352
CV	15.078481
N Missing	0

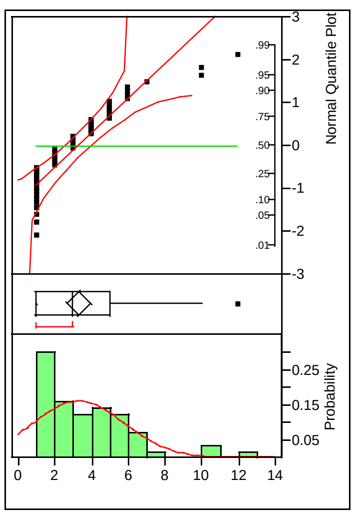
Relative Length



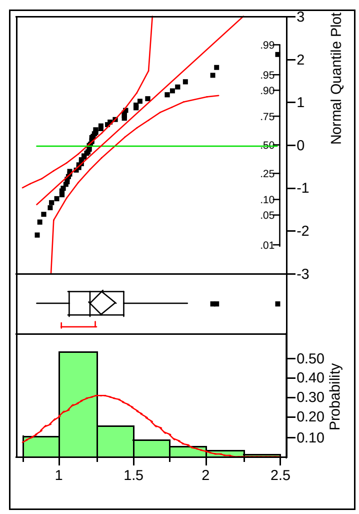
Mean Depth



Connectivity



Integration



Connectivity	
Mean	3.3214286
Std Dev	2.4797884
Std Err Mean	0.3313757
upper 95% Mean	3.9855202
lower 95% Mean	2.6573369
N	56
Sum Wgt	56
Sum	186
Variance	6.1493506
Skewness	1.4565817
Kurtosis	2.5237304
CV	74.660297
N Missing	0

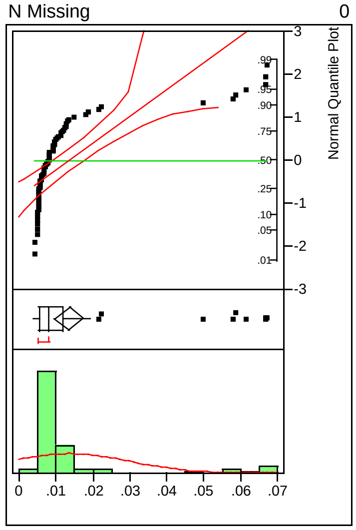
Integration	
Mean	1.2914464
Std Dev	0.320718
Std Err Mean	0.0428577
upper 95% Mean	1.3773353
lower 95% Mean	1.2055576
N	56
Sum Wgt	56
Sum	72.321
Variance	0.10286
Skewness	1.5671178
Kurtosis	3.0010527
CV	24.834015
N Missing	0

5) L5: a-london

Figure 6.2 continued: (L5).

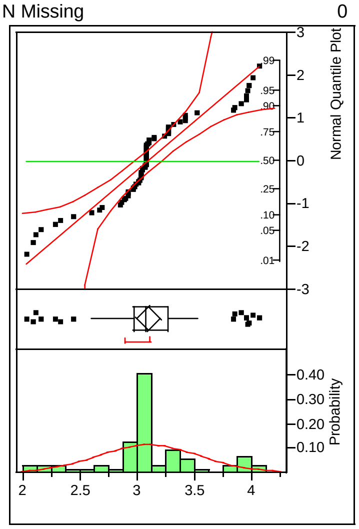
Relative Length

Mean	0.0136986
Std Dev	0.016191
Std Err Mean	0.001895
upper 95% Mean	0.0174763
lower 95% Mean	0.009921
N	73
Sum Wgt	73
Sum	1
Variance	0.0002621
Skewness	2.6073434
Kurtosis	5.5471036
CV	118.19437
N Missing	0

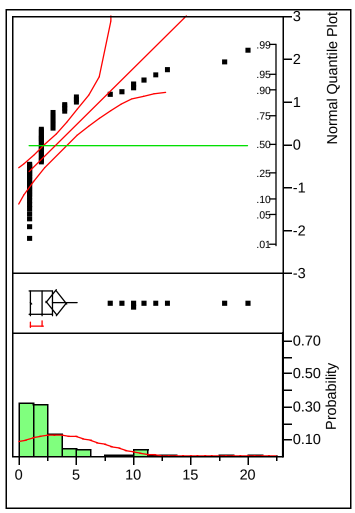


Mean Depth

Mean	3.1065342
Std Dev	0.4408398
Std Err Mean	0.0515964
upper 95% Mean	3.2093898
lower 95% Mean	3.0036787
N	73
Sum Wgt	73
Sum	226.777
Variance	0.1943398
Skewness	0.0262063
Kurtosis	0.882873
CV	14.190728
N Missing	0

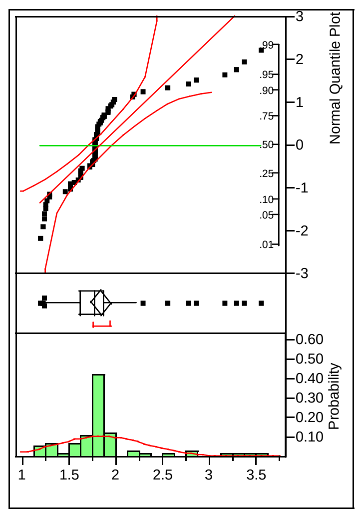


Connectivity



Mean	3.3150685
Std Dev	3.8110829
Std Err Mean	0.4460535
upper 95% Mean	4.2042599
lower 95% Mean	2.4258771
N	73
Sum Wgt	73
Sum	242
Variance	14.524353
Skewness	2.6773896
Kurtosis	7.4819254
CV	114.96242
N Missing	0

Integration



5

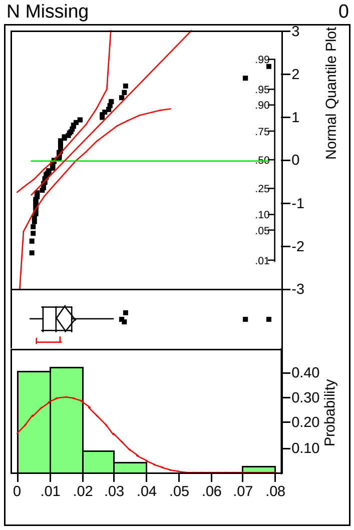
Mean	1.8518904
Std Dev	0.4756224
Std Err Mean	0.0556674
upper 95% Mean	1.9628613
lower 95% Mean	1.7409195
N	73
Sum Wgt	73
Sum	135.188
Variance	0.2262167
Skewness	1.8733171
Kurtosis	4.187988
CV	25.683077
N Missing	0

6) L6: apicorp

Figure 6.2 continued: (L6).

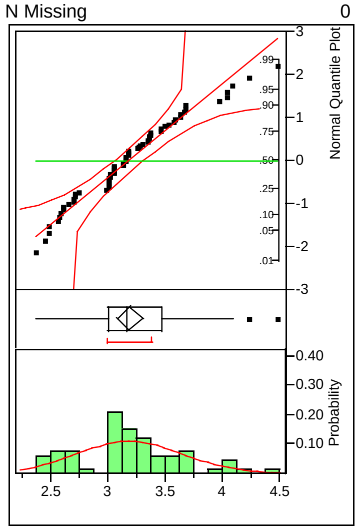
Relative Length

Mean	0.0151515
Std Dev	0.0130539
Std Err Mean	0.0016068
upper 95% Mean	0.0183606
lower 95% Mean	0.0119425
N	66
Sum Wgt	66
Sum	1
Variance	0.0001704
Skewness	3.1133529
Kurtosis	11.982997
CV	86.155642
N Missing	0

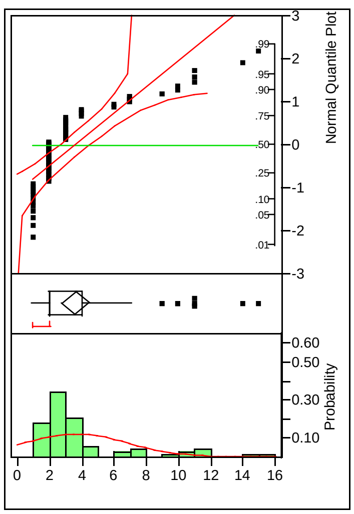


Mean Depth

Mean	3.1976818
Std Dev	0.4550475
Std Err Mean	0.0560125
upper 95% Mean	3.3095465
lower 95% Mean	3.0858172
N	66
Sum Wgt	66
Sum	211.047
Variance	0.2070682
Skewness	0.5160224
Kurtosis	0.2585629
CV	14.230543
N Missing	0

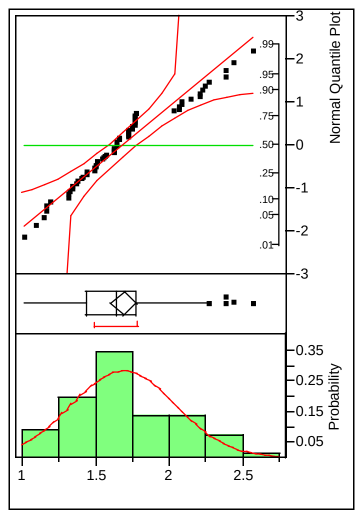


Connectivity



Mean	3.6363636
Std Dev	3.2939869
Std Err Mean	0.4054618
upper 95% Mean	4.4461267
lower 95% Mean	2.8266006
N	66
Sum Wgt	66
Sum	240
Variance	10.85035
Skewness	1.8930385
Kurtosis	2.9233312
CV	90.58464
N Missing	0

Integration



Mean	1.6948788
Std Dev	0.3529416
Std Err Mean	0.0434441
upper 95% Mean	1.7816427
lower 95% Mean	1.6081149
N	66
Sum Wgt	66
Sum	111.862
Variance	0.1245678
Skewness	0.5314864
Kurtosis	-0.157696
CV	20.824002
N Missing	0

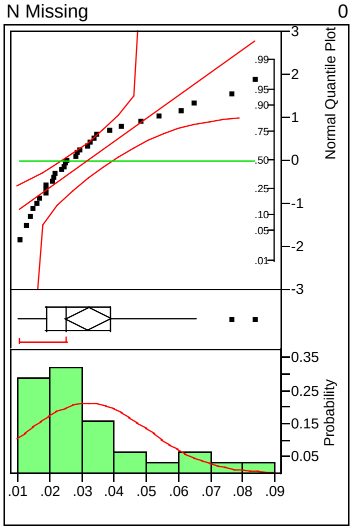
7) L7: apple

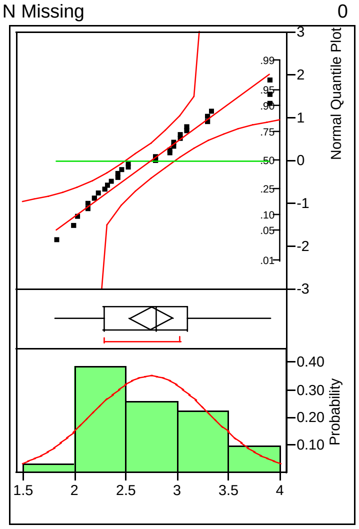
Figure 6.2 continued: (L7).

Mean	0.0322581
Std Dev	0.0188102
Std Err Mean	0.0033784
upper 95% Mean	0.0391577
lower 95% Mean	0.0253584
N	31
Sum Wgt	31
Sum	1
Variance	0.0003538
Skewness	1.3886639
Kurtosis	1.346272
CV	58.311537
N Missing	0

Mean	2.7504194
Std Dev	0.5665888
Std Err Mean	0.1017623
upper 95% Mean	2.9582458
lower 95% Mean	2.5425929
N	31
Sum Wgt	31
Sum	85.263
Variance	0.3210229
Skewness	0.5059953
Kurtosis	-0.379222
CV	20.600087
N Missing	0

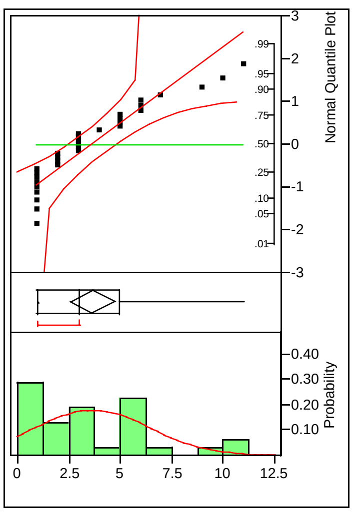
Relative Length

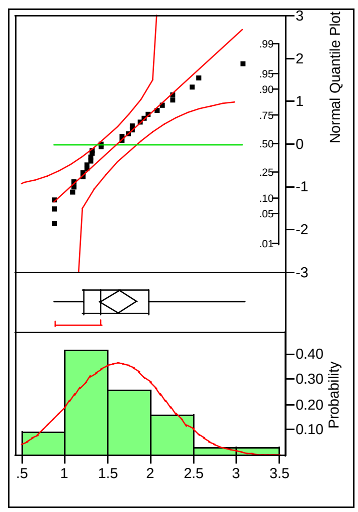




Mean Depth

Connectivity





Integration

Mean	3.6774194
Std Dev	2.7974643
Std Err Mean	0.5024394
upper 95% Mean	4.7035375
lower 95% Mean	2.6513012
N	31
Sum Wgt	31
Sum	114
Variance	7.8258065
Skewness	1.1169294
Kurtosis	0.6595094
CV	76.071397
N Missing	0

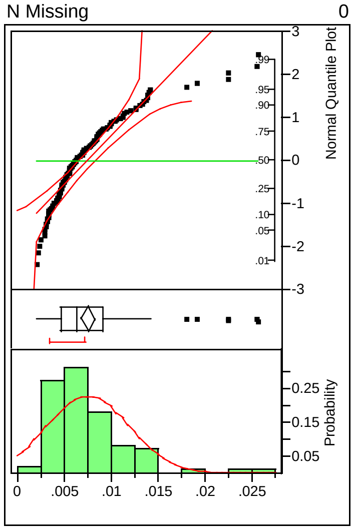
Mean	1.6312258
Std Dev	0.5455534
Std Err Mean	0.0979843
upper 95% Mean	1.8313364
lower 95% Mean	1.4311152
N	31
Sum Wgt	31
Sum	50.568
Variance	0.2976285
Skewness	0.7510543
Kurtosis	0.1741583
CV	33.444383
N Missing	0

8) L8: a-prague

Figure 6.2 continued: (L8).

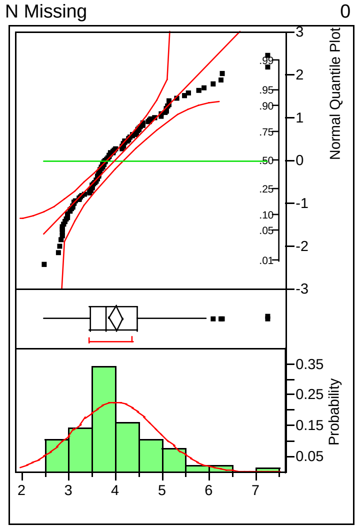
Relative Length

Mean	0.0076336
Std Dev	0.004428
Std Err Mean	0.0003869
upper 95% Mean	0.008399
lower 95% Mean	0.0068682
N	131
Sum Wgt	131
Sum	1
Variance	0.0000196
Skewness	1.9142482
Kurtosis	4.6689321
CV	58.006852
N Missing	0

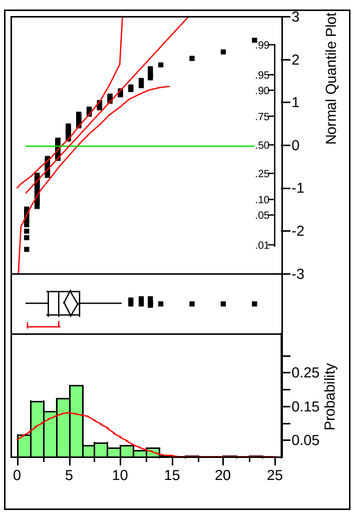


Mean Depth

Mean	4.021626
Std Dev	0.8819546
Std Err Mean	0.0770567
upper 95% Mean	4.1740735
lower 95% Mean	3.8691784
N	131
Sum Wgt	131
Sum	526.833
Variance	0.777844
Skewness	1.1755845
Kurtosis	1.9319291
CV	21.9303
N Missing	0

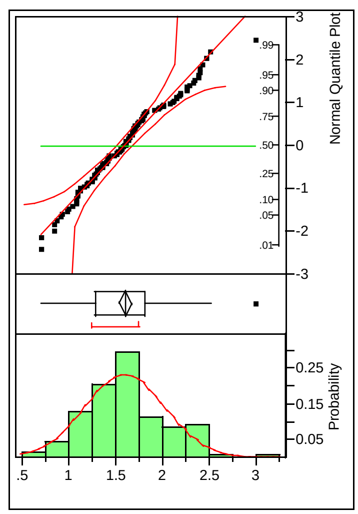


Connectivity



Mean	5.221374
Std Dev	3.8276124
Std Err Mean	0.33442
upper 95% Mean	5.8829841
lower 95% Mean	4.559764
N	131
Sum Wgt	131
Sum	684
Variance	14.650617
Skewness	1.8686824
Kurtosis	4.60505
CV	73.306611
N Missing	0

Integration



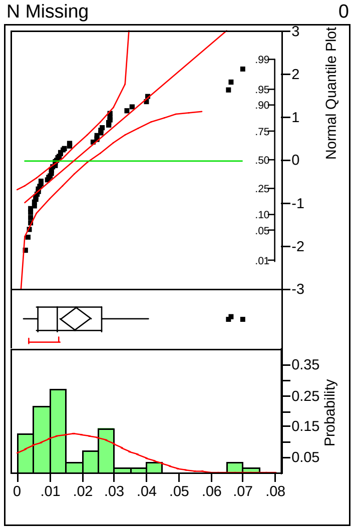
Mean	1.6094809
Std Dev	0.4299459
Std Err Mean	0.0375645
upper 95% Mean	1.6837979
lower 95% Mean	1.5351639
N	131
Sum Wgt	131
Sum	210.842
Variance	0.1848535
Skewness	0.4266027
Kurtosis	0.069401
CV	26.713327
N Missing	0

9) L9: buch

Figure 6.2 continued: (L9).

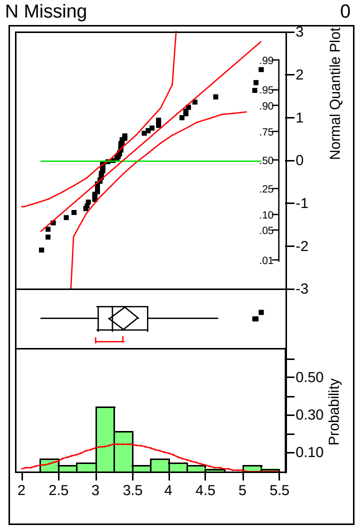
Relative Length

Mean	0.0181818
Std Dev	0.015705
Std Err Mean	0.0021177
upper 95% Mean	0.0224275
lower 95% Mean	0.0139362
N	55
Sum Wgt	55
Sum	1
Variance	0.0002466
Skewness	1.7785394
Kurtosis	3.3375268
CV	86.377347
N Missing	0

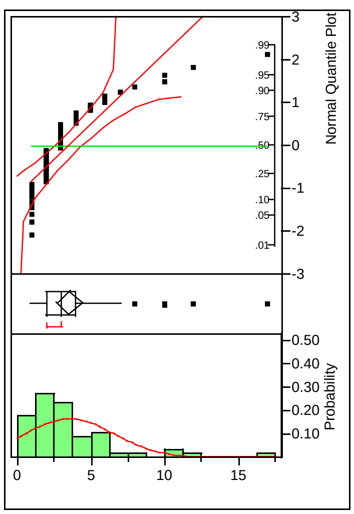


Mean Depth

Mean	3.3918727
Std Dev	0.6700071
Std Err Mean	0.0903437
upper 95% Mean	3.573001
lower 95% Mean	3.2107444
N	55
Sum Wgt	55
Sum	186.553
Variance	0.4489096
Skewness	1.1109893
Kurtosis	1.3012718
CV	19.75331
N Missing	0

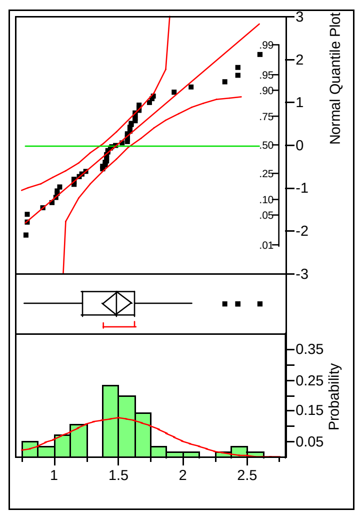


Connectivity



Mean	3.5636364
Std Dev	3.0353695
Std Err Mean	0.4092891
upper 95% Mean	4.3842117
lower 95% Mean	2.743061
N	55
Sum Wgt	55
Sum	196
Variance	9.213468
Skewness	2.4132251
Kurtosis	7.1286273
CV	85.176185
N Missing	0

Integration



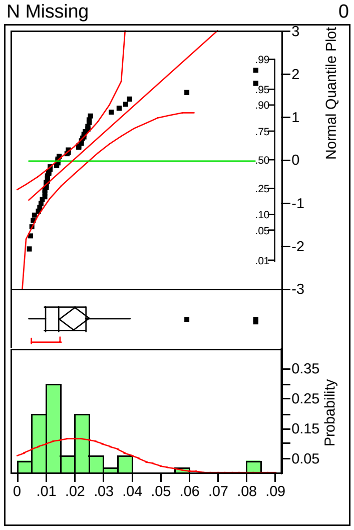
Mean	1.4904
Std Dev	0.3906712
Std Err Mean	0.0526781
upper 95% Mean	1.5960132
lower 95% Mean	1.3847868
N	55
Sum Wgt	55
Sum	81.972
Variance	0.1526239
Skewness	0.6716556
Kurtosis	1.15881
CV	26.212503
N Missing	0

10) L10: chase

Figure 6.2 continued: (L10).

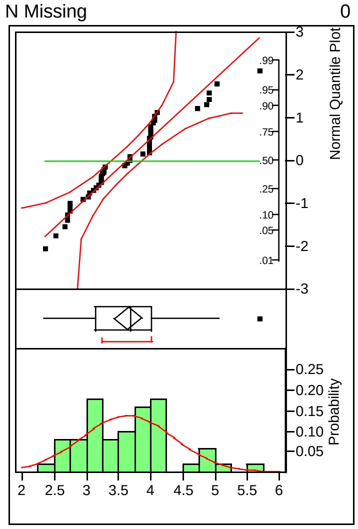
Relative Length

Mean	0.02
Std Dev	0.0168102
Std Err Mean	0.0023773
upper 95% Mean	0.0247774
lower 95% Mean	0.0152226
N	50
Sum Wgt	50
Sum	1
Variance	0.0002826
Skewness	2.4781515
Kurtosis	7.0067102
CV	84.050951
N Missing	0

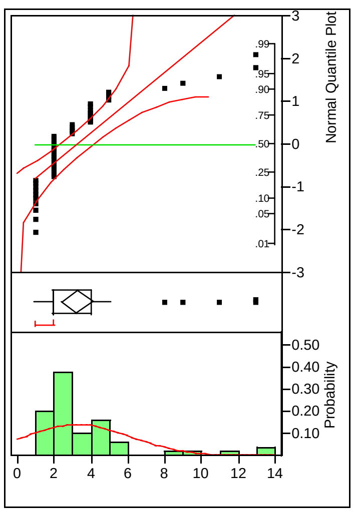


Mean Depth

Mean	3.65222
Std Dev	0.7201478
Std Err Mean	0.1018443
upper 95% Mean	3.8568837
lower 95% Mean	3.4475563
N	50
Sum Wgt	50
Sum	182.611
Variance	0.5186129
Skewness	0.5421559
Kurtosis	0.2744183
CV	19.718084
N Missing	0

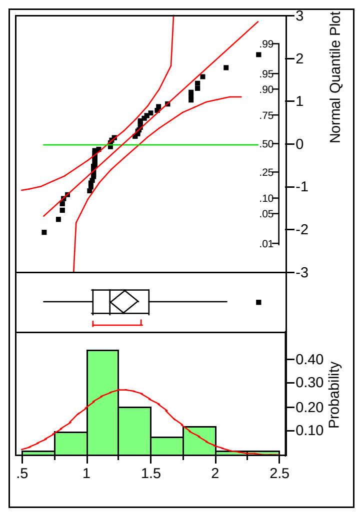


Connectivity



Mean	3.28
Std Dev	2.8574286
Std Err Mean	0.4041014
upper 95% Mean	4.0920722
lower 95% Mean	2.4679278
N	50
Sum Wgt	50
Sum	164
Variance	8.164898
Skewness	2.2313418
Kurtosis	4.8766863
CV	87.116724
N Missing	0

Integration



Mean	1.2981
Std Dev	0.3648512
Std Err Mean	0.0515978
upper 95% Mean	1.4017896
lower 95% Mean	1.1944104
N	50
Sum Wgt	50
Sum	64.905
Variance	0.1331164
Skewness	0.7688661
Kurtosis	0.2401144
CV	28.106558
N Missing	0

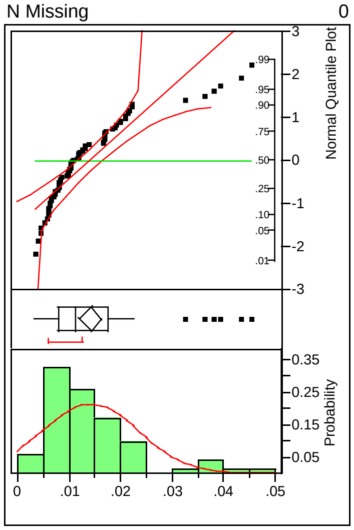
11) L11: chiat-ca

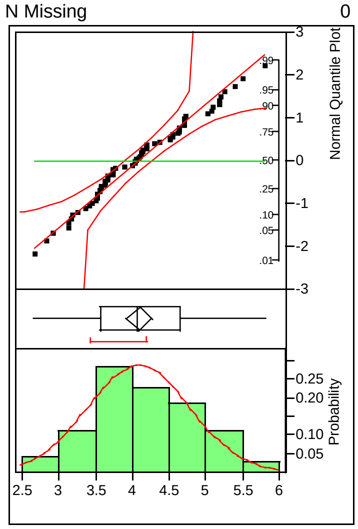
Figure 6.2 continued: (L11).

Mean	0.0142857
Std Dev	0.0093634
Std Err Mean	0.0011191
upper 95% Mean	0.0165183
lower 95% Mean	0.0120531
N	70
Sum Wgt	70
Sum	1
Variance	0.0000877
Skewness	1.7200218
Kurtosis	2.90739
CV	65.543815
N Missing	0

Mean	4.1031286
Std Dev	0.6943203
Std Err Mean	0.0829872
upper 95% Mean	4.2686834
lower 95% Mean	3.9375737
N	70
Sum Wgt	70
Sum	287.219
Variance	0.4820807
Skewness	0.3147932
Kurtosis	-0.470993
CV	16.92173
N Missing	0

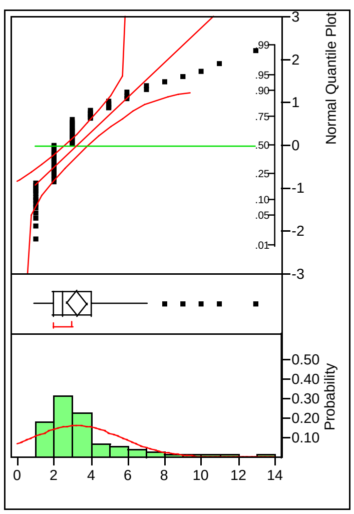
Relative Length

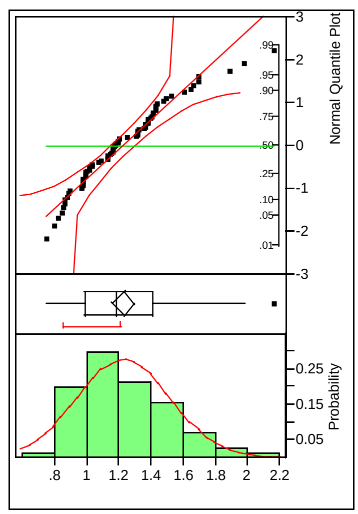




Mean Depth

Connectivity





Integration

Mean	3.2571429
Std Dev	2.4770583
Std Err Mean	0.2960651
upper 95% Mean	3.8477766
lower 95% Mean	2.6665092
N	70
Sum Wgt	70
Sum	228
Variance	6.1358178
Skewness	1.9516116
Kurtosis	4.112494
CV	76.050035
N Missing	0

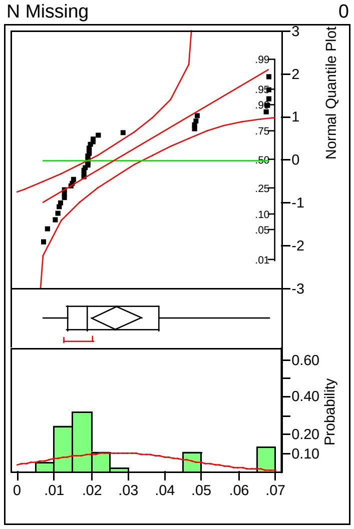
Mean	1.2379714
Std Dev	0.2894365
Std Err Mean	0.0345943
upper 95% Mean	1.3069851
lower 95% Mean	1.1689577
N	70
Sum Wgt	70
Sum	86.658
Variance	0.0837735
Skewness	0.791955
Kurtosis	0.7835629
CV	23.379904
N Missing	0

12) L12: chiat-ny

Figure 6.2 continued: (L12).

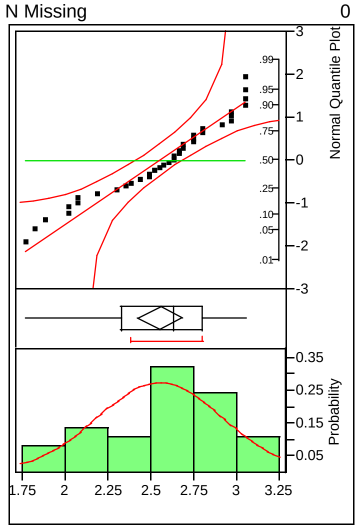
Relative Length

Mean	0.027027
Std Dev	0.019677
Std Err Mean	0.0032349
upper 95% Mean	0.0335876
lower 95% Mean	0.0204664
N	37
Sum Wgt	37
Sum	1
Variance	0.0003872
Skewness	1.2945915
Kurtosis	0.2082128
CV	72.804717
N Missing	0

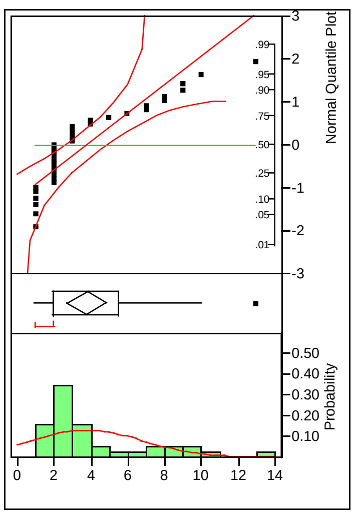


Mean Depth

Mean	2.5571081
Std Dev	0.3660829
Std Err Mean	0.0601837
upper 95% Mean	2.6791662
lower 95% Mean	2.43505
N	37
Sum Wgt	37
Sum	94.613
Variance	0.1340167
Skewness	-0.550109
Kurtosis	-0.543339
CV	14.316284
N Missing	0

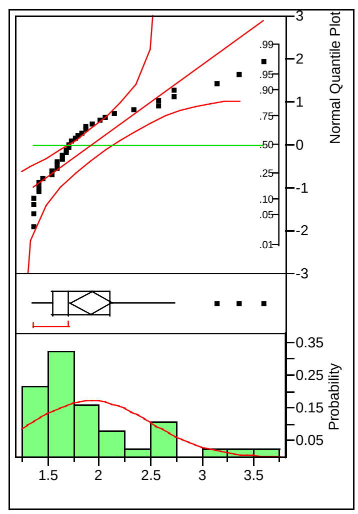


Connectivity



Mean	3.7837838
Std Dev	3.038047
Std Err Mean	0.4994519
upper 95% Mean	4.7967191
lower 95% Mean	2.7708485
N	37
Sum Wgt	37
Sum	140
Variance	9.2297297
Skewness	1.3927299
Kurtosis	1.1844556
CV	80.291243
N Missing	0

Integration



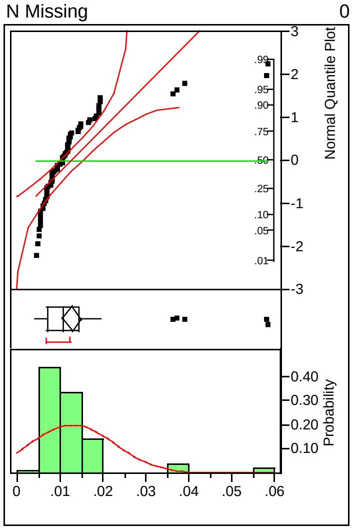
Mean	1.9280811
Std Dev	0.5795618
Std Err Mean	0.0952794
upper 95% Mean	2.1213166
lower 95% Mean	1.7348455
N	37
Sum Wgt	37
Sum	71.339
Variance	0.3358919
Skewness	1.4588277
Kurtosis	1.4974484
CV	30.058997
N Missing	0

13) L13: citicorp

Figure 6.2 continued: (L13).

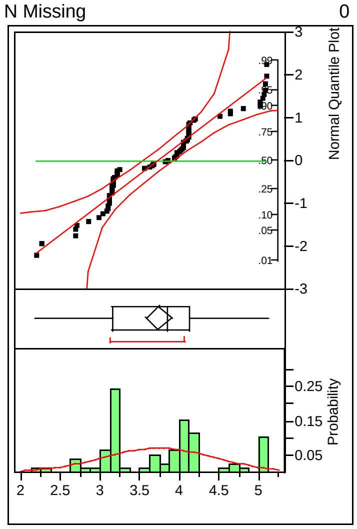
Relative Length

Mean	0.012987
Std Dev	0.0100038
Std Err Mean	0.00114
upper 95% Mean	0.0152576
lower 95% Mean	0.0107164
N	77
Sum Wgt	77
Sum	1
Variance	0.0001001
Skewness	3.0679864
Kurtosis	10.729405
CV	77.029583
N Missing	0

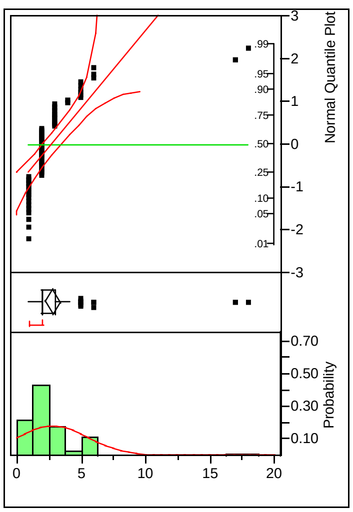


Mean Depth

Mean	3.7478052
Std Dev	0.7117899
Std Err Mean	0.081116
upper 95% Mean	3.9093617
lower 95% Mean	3.5862487
N	77
Sum Wgt	77
Sum	288.581
Variance	0.5066449
Skewness	0.233517
Kurtosis	-0.531121
CV	18.99218
N Missing	0

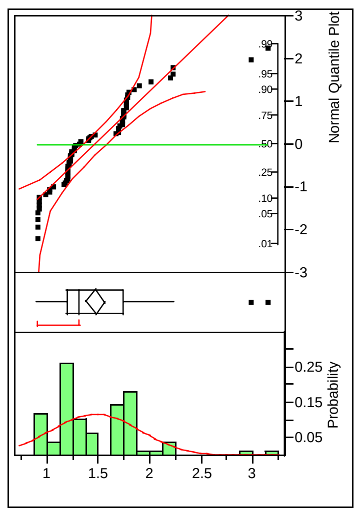


Connectivity



Mean	2.8051948
Std Dev	2.7436
Std Err Mean	0.3126622
upper 95% Mean	3.4279156
lower 95% Mean	2.182474
N	77
Sum Wgt	77
Sum	216
Variance	7.5273411
Skewness	4.1967306
Kurtosis	20.639937
CV	97.80426
N Missing	0

Integration



Mean	1.4787922
Std Dev	0.4304735
Std Err Mean	0.049057
upper 95% Mean	1.5764977
lower 95% Mean	1.3810867
N	77
Sum Wgt	77
Sum	113.867
Variance	0.1853074
Skewness	1.3706733
Kurtosis	3.268637
CV	29.109801
N Missing	0

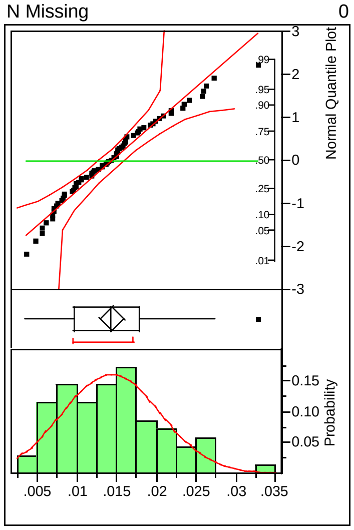
14) L14: commerz

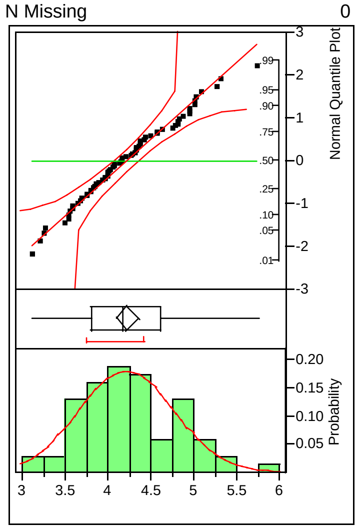
Figure 6.2 continued: (L14).

Mean	0.0144928
Std Dev	0.0061985
Std Err Mean	0.0007462
upper 95% Mean	0.0159818
lower 95% Mean	0.0130037
N	69
Sum Wgt	69
Sum	1
Variance	0.0000384
Skewness	0.58982
Kurtosis	0.0762788
CV	42.769704
N Missing	0

Mean	4.2331739
Std Dev	0.5575808
Std Err Mean	0.0671248
upper 95% Mean	4.3671195
lower 95% Mean	4.0992284
N	69
Sum Wgt	69
Sum	292.089
Variance	0.3108964
Skewness	0.316454
Kurtosis	-0.264751
CV	13.171697
N Missing	0

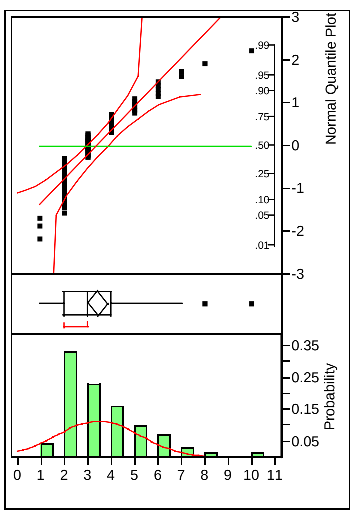
Relative Length

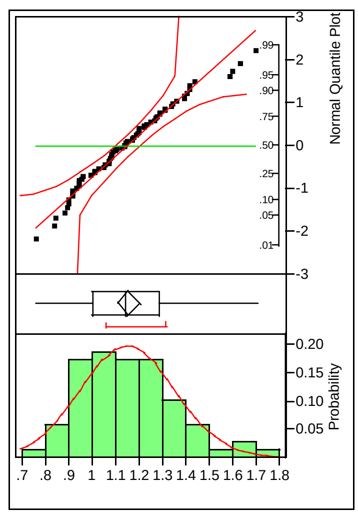




Mean Depth

Connectivity





Integration

Mean	3.4492754
Std Dev	1.7618192
Std Err Mean	0.2120981
upper 95% Mean	3.8725105
lower 95% Mean	3.0260402
N	69
Sum Wgt	69
Sum	238
Variance	3.1040068
Skewness	1.274614
Kurtosis	1.9501571
CV	51.077951
N Missing	0

Mean	1.157058
Std Dev	0.2027572
Std Err Mean	0.0244091
upper 95% Mean	1.2057656
lower 95% Mean	1.1083504
N	69
Sum Wgt	69
Sum	79.837
Variance	0.0411105
Skewness	0.5189373
Kurtosis	0.0534886
CV	17.523516
N Missing	0

15) L15: datapec

Figure 6.2 continued: (L15).

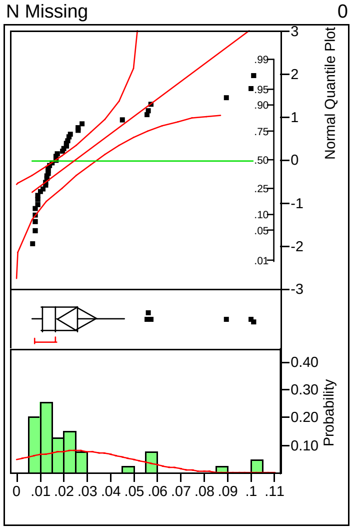
Relative Length

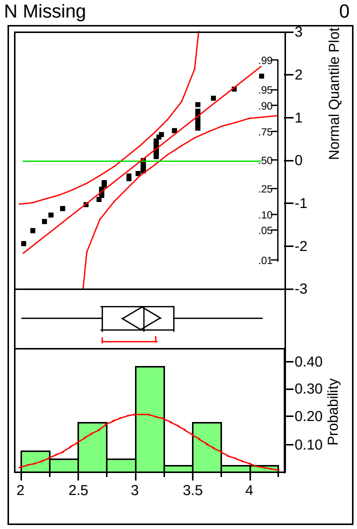
Mean	0.025641
Std Dev	0.0247502
Std Err Mean	0.0039632
upper 95% Mean	0.0336641
lower 95% Mean	0.0176179
N	39
Sum Wgt	39
Sum	1
Variance	0.0006126
Skewness	2.106096
Kurtosis	3.7671805
CV	96.525845
N Missing	0

Mean Depth

Mean	3.0566923
Std Dev	0.4764112
Std Err Mean	0.0762868
upper 95% Mean	3.211127
lower 95% Mean	2.9022577
N	39
Sum Wgt	39
Sum	119.211
Variance	0.2269676
Skewness	-0.263558
Kurtosis	-0.028998
CV	15.585841
N Missing	0

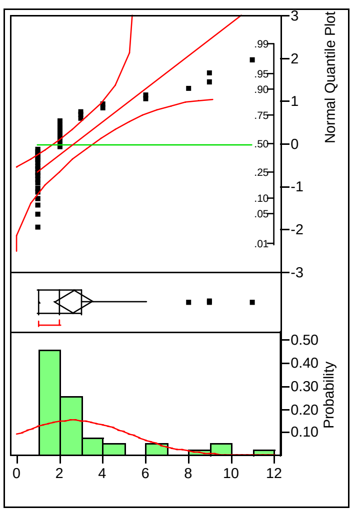
Relative Length

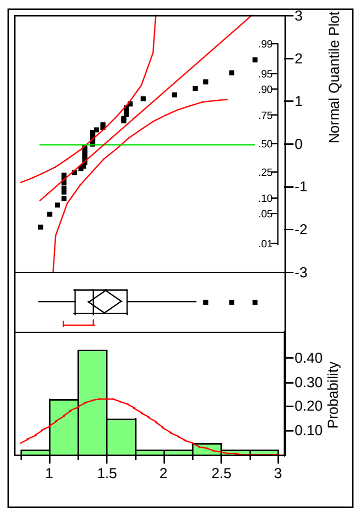




Mean Depth

Connectivity





Integration

Connectivity

Mean	2.6666667
Std Dev	2.6090262
Std Err Mean	0.4177785
upper 95% Mean	3.5124151
lower 95% Mean	1.8209182
N	39
Sum Wgt	39
Sum	104
Variance	6.8070175
Skewness	1.9228315
Kurtosis	2.8961474
CV	97.838481
N Missing	0

Integration

Mean	1.4882564
Std Dev	0.4285704
Std Err Mean	0.0686262
upper 95% Mean	1.6271829
lower 95% Mean	1.3493299
N	39
Sum Wgt	39
Sum	58.042
Variance	0.1836726
Skewness	1.5368902
Kurtosis	2.1526284
CV	28.796814
N Missing	0

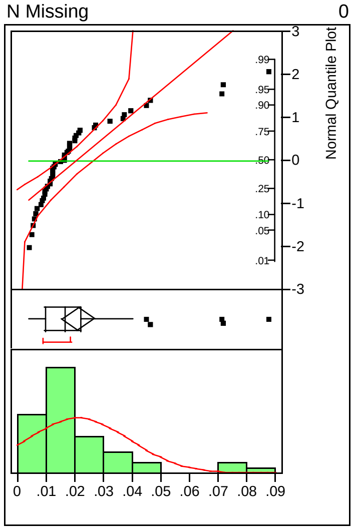
16) L16: davis

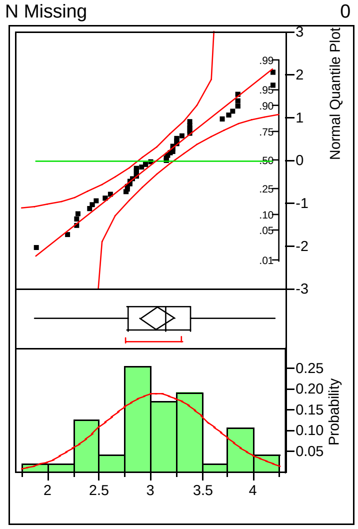
Figure 6.2 continued: (L16).

Mean	0.0212766
Std Dev	0.0181101
Std Err Mean	0.0026416
upper 95% Mean	0.0265939
lower 95% Mean	0.0159593
N	47
Sum Wgt	47
Sum	1
Variance	0.000328
Skewness	2.147086
Kurtosis	4.7336878
CV	85.117291
N Missing	0

Mean	3.0666383
Std Dev	0.5283164
Std Err Mean	0.0770629
upper 95% Mean	3.2217578
lower 95% Mean	2.9115188
N	47
Sum Wgt	47
Sum	144.132
Variance	0.2791182
Skewness	0.1092782
Kurtosis	-0.246341
CV	17.227867
N Missing	0

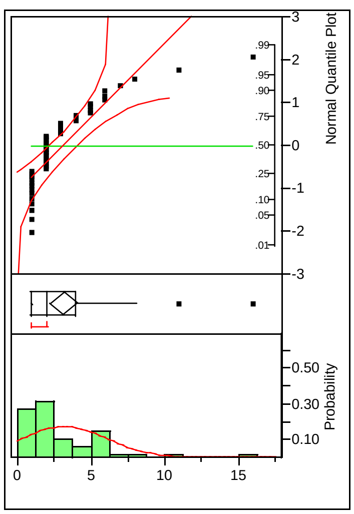
Relative Length

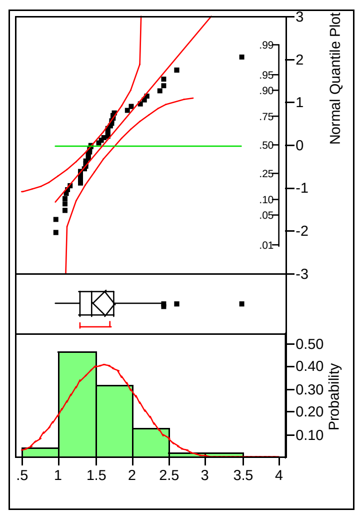




Mean Depth

Connectivity





Integration

Mean	3.1914894
Std Dev	2.8940591
Std Err Mean	0.4221419
upper 95% Mean	4.041217
lower 95% Mean	2.3417618
N	47
Sum Wgt	47
Sum	150
Variance	8.3755782
Skewness	2.5041461
Kurtosis	8.0711345
CV	90.680519
N Missing	0

Mean	1.622766
Std Dev	0.4895206
Std Err Mean	0.0714039
upper 95% Mean	1.7664946
lower 95% Mean	1.4790373
N	47
Sum Wgt	47
Sum	76.27
Variance	0.2396304
Skewness	1.5501245
Kurtosis	3.5376118
CV	30.165818
N Missing	0

17) L17: degw

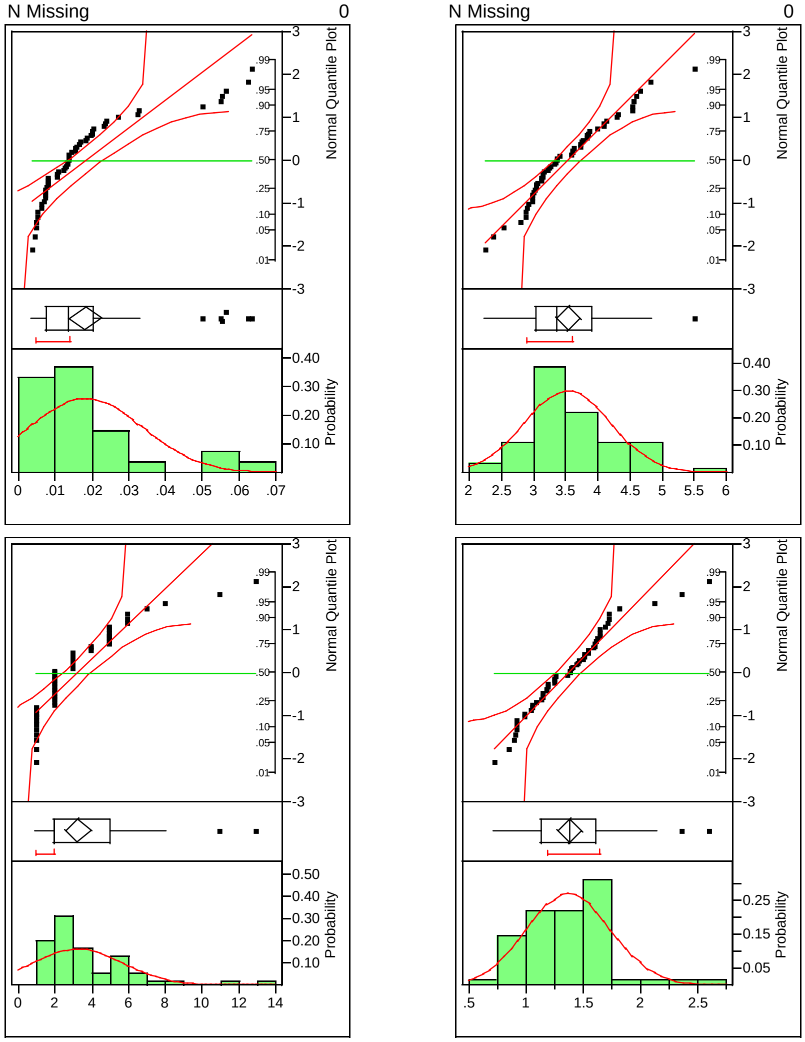
Figure 6.2 continued: (L17).

Relative Length

Mean	0.0185185
Std Dev	0.0155131
Std Err Mean	0.0021111
upper 95% Mean	0.0227528
lower 95% Mean	0.0142843
N	54
Sum Wgt	54
Sum	1
Variance	0.0002407
Skewness	1.7888267
Kurtosis	2.4217594
CV	83.7707
N Missing	0

Mean Depth

Mean	3.5520926
Std Dev	0.6664616
Std Err Mean	0.0906939
upper 95% Mean	3.7340016
lower 95% Mean	3.3701836
N	54
Sum Wgt	54
Sum	191.813
Variance	0.4441711
Skewness	0.6380252
Kurtosis	0.2866206
CV	18.762506
N Missing	0



Connectivity

Mean	3.2592593
Std Dev	2.458602
Std Err Mean	0.3345734
upper 95% Mean	3.9303284
lower 95% Mean	2.5881901
N	54
Sum Wgt	54
Sum	176
Variance	6.044724
Skewness	1.9589988
Kurtosis	4.8362875
CV	75.434381
N Missing	0

Integration

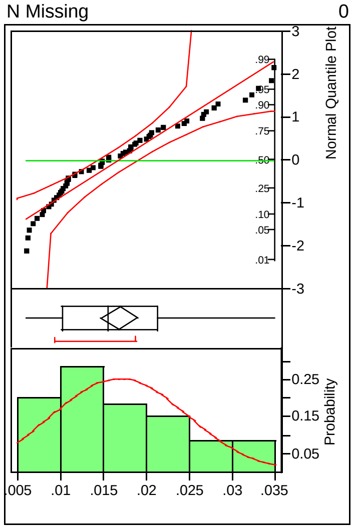
Mean	1.3826111
Std Dev	0.3685855
Std Err Mean	0.0501581
upper 95% Mean	1.4832156
lower 95% Mean	1.2820066
N	54
Sum Wgt	54
Sum	74.661
Variance	0.1358553
Skewness	0.9217295
Kurtosis	1.6888954
CV	26.658652
N Missing	0

18) L18: discovery

Figure 6.2 continued: (L18).

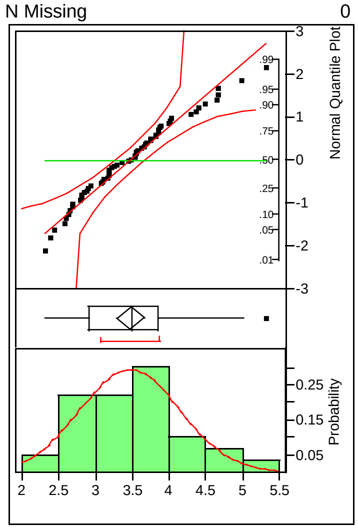
Relative Length

Mean	0.0169492
Std Dev	0.0078685
Std Err Mean	0.0010244
upper 95% Mean	0.0189997
lower 95% Mean	0.0148986
N	59
Sum Wgt	59
Sum	1
Variance	0.0000619
Skewness	0.6594655
Kurtosis	-0.435221
CV	46.423942
N Missing	0

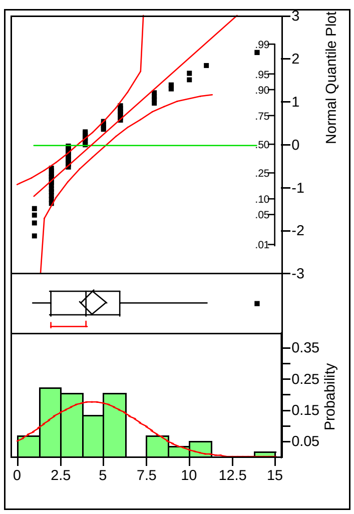


Mean Depth

Mean	3.4857288
Std Dev	0.6804669
Std Err Mean	0.0885892
upper 95% Mean	3.6630595
lower 95% Mean	3.3083982
N	59
Sum Wgt	59
Sum	205.658
Variance	0.4630352
Skewness	0.5123075
Kurtosis	-0.088385
CV	19.52151
N Missing	0

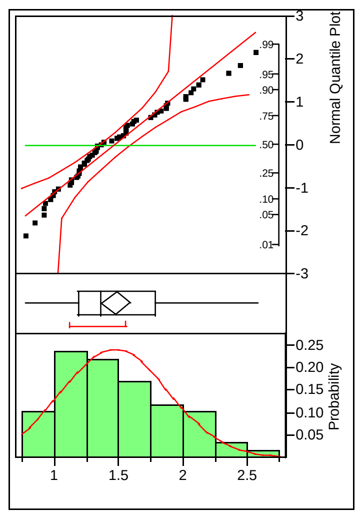


Connectivity



Mean	4.4067797
Std Dev	2.8108082
Std Err Mean	0.3659361
upper 95% Mean	5.1392803
lower 95% Mean	3.674279
N	59
Sum Wgt	59
Sum	260
Variance	7.9006429
Skewness	1.2495013
Kurtosis	1.4153713
CV	63.783725
N Missing	0

Integration



Mean	1.4823729
Std Dev	0.4154987
Std Err Mean	0.0540933
upper 95% Mean	1.5906524
lower 95% Mean	1.3740933
N	59
Sum Wgt	59
Sum	87.46
Variance	0.1726392
Skewness	0.66736
Kurtosis	-0.080298
CV	28.0293
N Missing	0

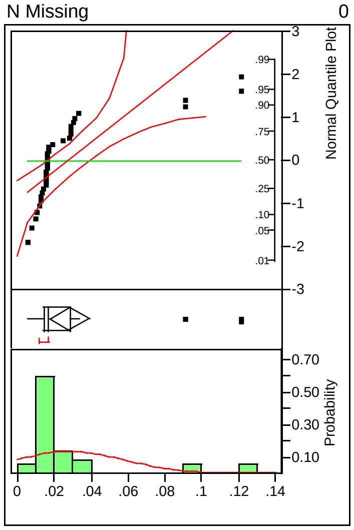
19) L19: dupont

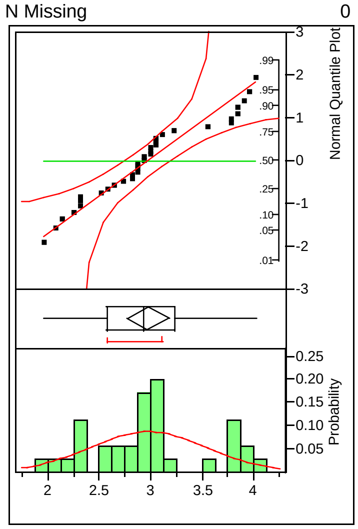
Figure 6.2 continued: (L19).

Mean	0.0285714
Std Dev	0.0297711
Std Err Mean	0.0050322
upper 95% Mean	0.0387982
lower 95% Mean	0.0183447
N	35
Sum Wgt	35
Sum	1
Variance	0.0008863
Skewness	2.4302555
Kurtosis	4.96865
CV	104.19887
N Missing	0

Mean	2.9798571
Std Dev	0.5731175
Std Err Mean	0.0968745
upper 95% Mean	3.1767299
lower 95% Mean	2.7829844
N	35
Sum Wgt	35
Sum	104.295
Variance	0.3284637
Skewness	0.3021883
Kurtosis	-0.636933
CV	19.233052
N Missing	0

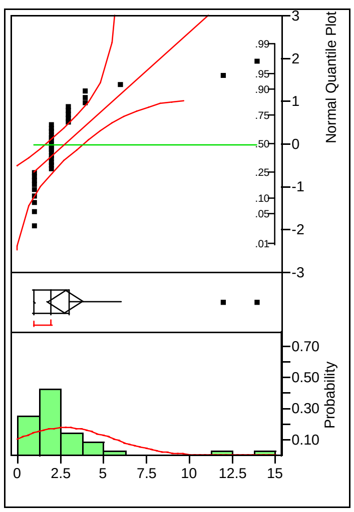
Relative Length

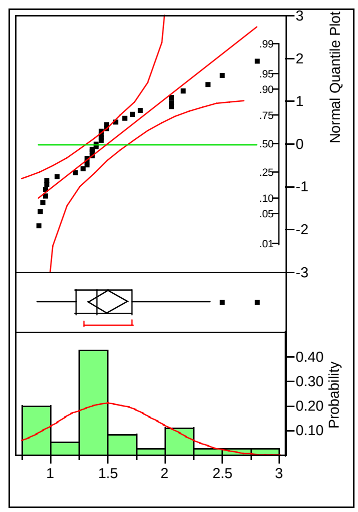




Mean Depth

Connectivity





Integration

Mean	2.8
Std Dev	2.7844104
Std Err Mean	0.4706513
upper 95% Mean	3.7564784
lower 95% Mean	1.8435216
N	35
Sum Wgt	35
Sum	98
Variance	7.7529412
Skewness	3.1233355
Kurtosis	10.208965
CV	99.443228
N Missing	0

Mean	1.5055429
Std Dev	0.4758741
Std Err Mean	0.0804374
upper 95% Mean	1.6690113
lower 95% Mean	1.3420744
N	35
Sum Wgt	35
Sum	52.694
Variance	0.2264561
Skewness	0.9808191
Kurtosis	0.6593733
CV	31.608139
N Missing	0

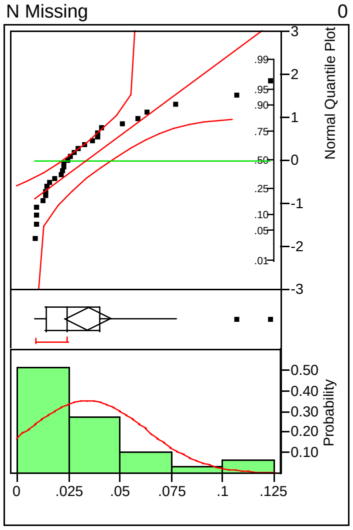
20) L20: equitable

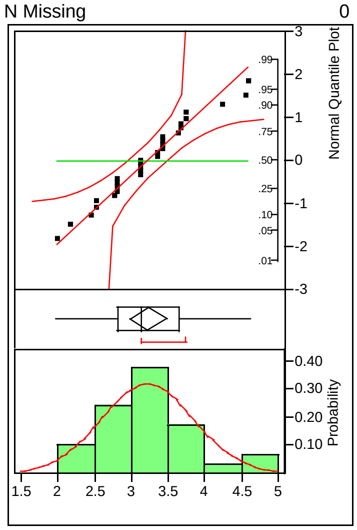
Figure 6.2 continued: (L20).

Relative Length	
Mean	0.0344828
Std Dev	0.0282792
Std Err Mean	0.0052513
upper 95% Mean	0.0452396
lower 95% Mean	0.0237259
N	29
Sum Wgt	29
Sum	1
Variance	0.0007997
Skewness	1.8557555
Kurtosis	3.4075722
CV	82.009714
N Missing	0

Mean Depth	
Mean	3.2365172
Std Dev	0.6299219
Std Err Mean	0.1169736
upper 95% Mean	3.4761267
lower 95% Mean	2.9969078
N	29
Sum Wgt	29
Sum	93.859
Variance	0.3968016
Skewness	0.2962677
Kurtosis	0.1887888
CV	19.462956
N Missing	0

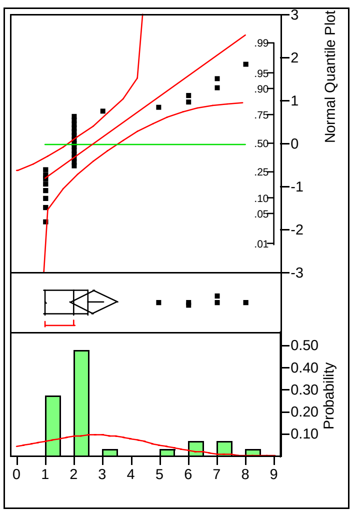
Relative Length

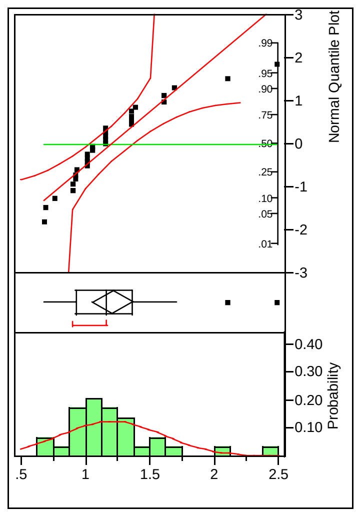




Mean Depth

Connectivity





Integration

Connectivity	
Mean	2.6896552
Std Dev	2.0891462
Std Err Mean	0.3879447
upper 95% Mean	3.4843239
lower 95% Mean	1.8949864
N	29
Sum Wgt	29
Sum	78
Variance	4.364532
Skewness	1.4793636
Kurtosis	0.8845249
CV	77.673386
N Missing	0

Integration	
Mean	1.2134828
Std Dev	0.4010878
Std Err Mean	0.0744801
upper 95% Mean	1.3660484
lower 95% Mean	1.0609171
N	29
Sum Wgt	29
Sum	35.191
Variance	0.1608714
Skewness	1.513305
Kurtosis	2.8934847
CV	33.052614
N Missing	0

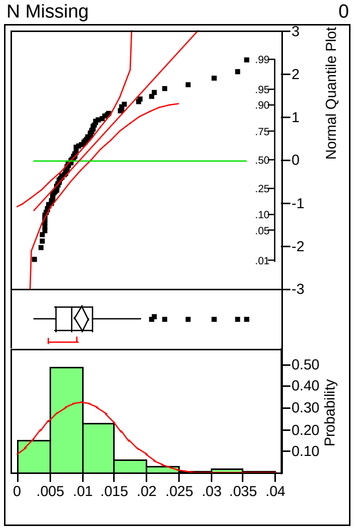
21) L21: ford-f

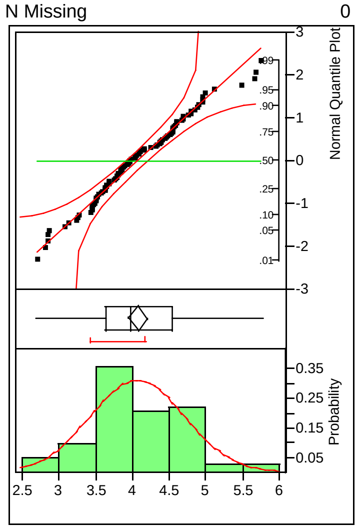
Figure 6.2 continued: (L21).

Mean	0.01
Std Dev	0.0060851
Std Err Mean	0.0006085
upper 95% Mean	0.0112074
lower 95% Mean	0.0087926
N	100
Sum Wgt	100
Sum	1
Variance	0.000037
Skewness	2.1941356
Kurtosis	5.8190751
CV	60.850934
N Missing	0

Mean	4.08432
Std Dev	0.6403614
Std Err Mean	0.0640361
upper 95% Mean	4.2113816
lower 95% Mean	3.9572584
N	100
Sum Wgt	100
Sum	408.432
Variance	0.4100628
Skewness	0.3040974
Kurtosis	0.0346438
CV	15.678533
N Missing	0

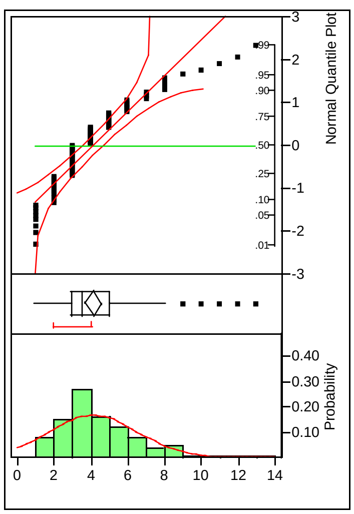
Relative Length

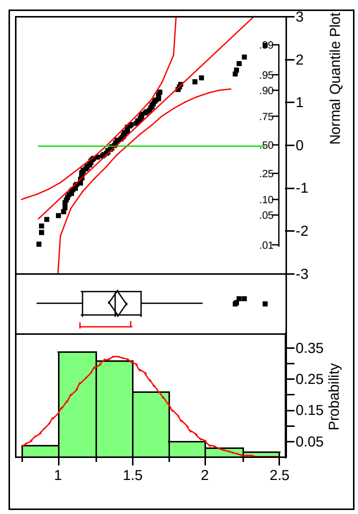




Mean Depth

Connectivity





Integration

Mean	4.14
Std Dev	2.4037849
Std Err Mean	0.2403785
upper 95% Mean	4.6169631
lower 95% Mean	3.6630369
N	100
Sum Wgt	100
Sum	414
Variance	5.7781818
Skewness	1.3546476
Kurtosis	2.2263013
CV	58.062437
N Missing	0

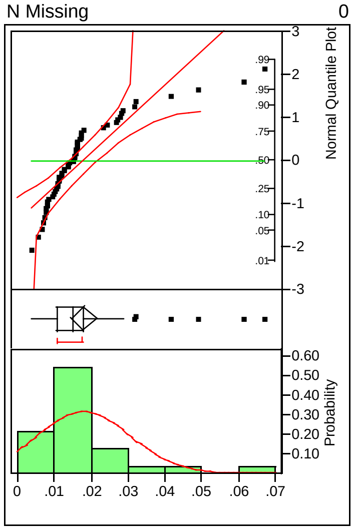
Mean	1.40304
Std Dev	0.3101739
Std Err Mean	0.0310174
upper 95% Mean	1.4645852
lower 95% Mean	1.3414948
N	100
Sum Wgt	100
Sum	140.304
Variance	0.0962079
Skewness	0.9549208
Kurtosis	1.2258574
CV	22.107275
N Missing	0

22) L22: ford-m

Figure 6.2 continued: (L22).

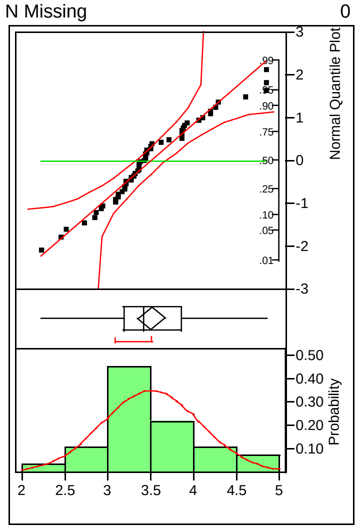
Mean	0.0181818
Std Dev	0.01268
Std Err Mean	0.0017098
upper 95% Mean	0.0216097
lower 95% Mean	0.0147539
N	55
Sum Wgt	55
Sum	1
Variance	0.0001608
Skewness	2.2317783
Kurtosis	5.585166
CV	69.740144
N Missing	0

Relative Length

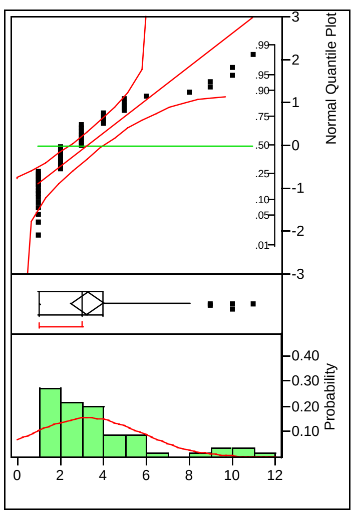


Mean	3.5185091
Std Dev	0.5724498
Std Err Mean	0.0771891
upper 95% Mean	3.6732639
lower 95% Mean	3.3637542
N	55
Sum Wgt	55
Sum	193.518
Variance	0.3276987
Skewness	0.4597537
Kurtosis	0.3752786
CV	16.269669
N Missing	0

Mean Depth

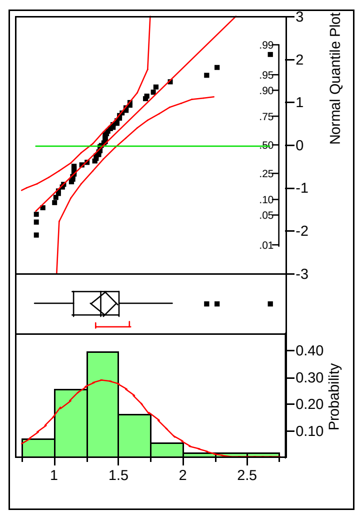


Connectivity



Mean	3.2727273
Std Dev	2.5852469
Std Err Mean	0.3485946
upper 95% Mean	3.9716174
lower 95% Mean	2.5738371
N	55
Sum Wgt	55
Sum	180
Variance	6.6835017
Skewness	1.555532
Kurtosis	1.8508195
CV	78.993656
N Missing	0

Integration



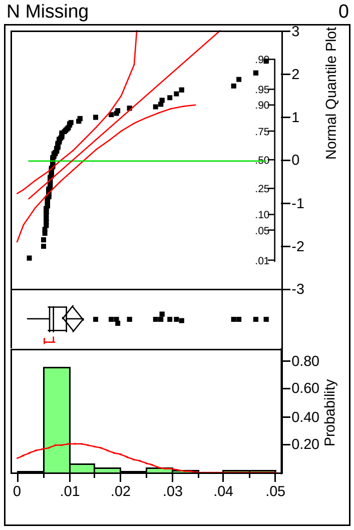
Mean	1.3925455
Std Dev	0.3430037
Std Err Mean	0.0462506
upper 95% Mean	1.4852723
lower 95% Mean	1.2998186
N	55
Sum Wgt	55
Sum	76.59
Variance	0.1176515
Skewness	1.3267714
Kurtosis	3.2793818
CV	24.631416
N Missing	0

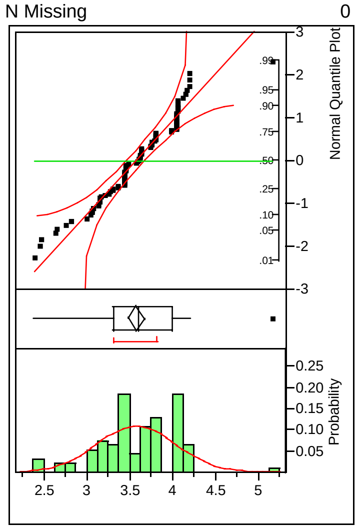
23) L23: fx

Figure 6.2 continued: (L23).

Mean	0.0108696	Mean	3.5896522
Std Dev	0.0095465	Std Dev	0.4577411
Std Err Mean	0.0009953	Std Err Mean	0.0477228
upper 95% Mean	0.0128466	upper 95% Mean	3.6844477
lower 95% Mean	0.0088925	lower 95% Mean	3.4948567
N	92	N	92
Sum Wgt	92	Sum Wgt	92
Sum	1	Sum	330.248
Variance	0.0000911	Variance	0.2095269
Skewness	2.5260477	Skewness	-0.140242
Kurtosis	5.8323646	Kurtosis	1.1303006
CV	87.827529	CV	12.751684
N Missing	0	N Missing	0

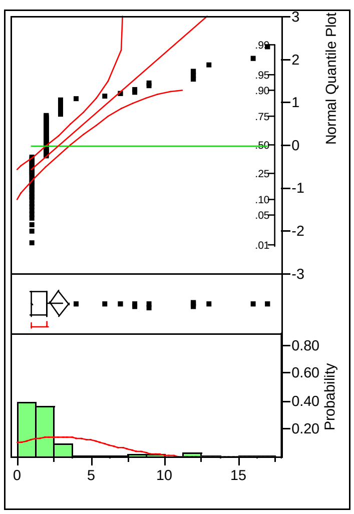
Relative Length

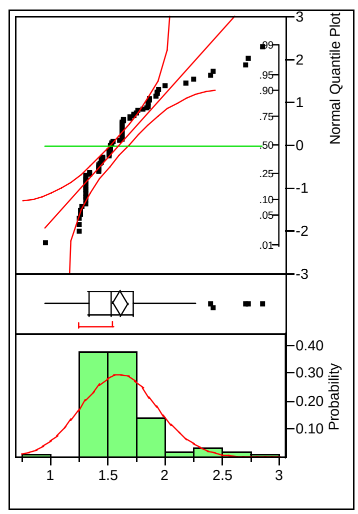




Mean Depth

Connectivity





Integration

Mean	2.8695652	Mean	1.6102174
Std Dev	3.3682989	Std Dev	0.3358332
Std Err Mean	0.3511694	Std Err Mean	0.035013
upper 95% Mean	3.5671202	upper 95% Mean	1.6797665
lower 95% Mean	2.1720103	lower 95% Mean	1.5406683
N	92	N	92
Sum Wgt	92	Sum Wgt	92
Sum	264	Sum	148.14
Variance	11.345437	Variance	0.1127839
Skewness	2.6408972	Skewness	1.639906
Kurtosis	6.5677191	Kurtosis	3.5021757
CV	117.38011	CV	20.856388
N Missing	0	N Missing	0

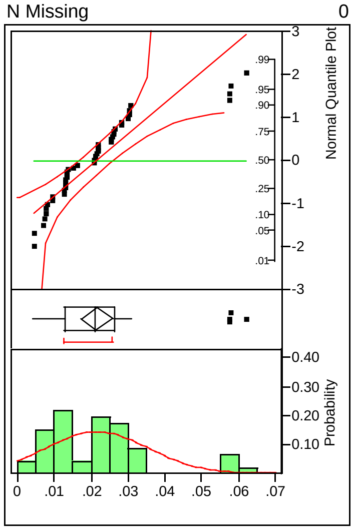
24) L24: greenberg

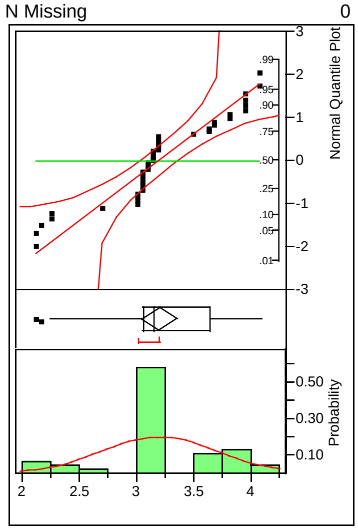
Figure 6.2 continued: (L24).

Mean	0.0217391
Std Dev	0.0139171
Std Err Mean	0.002052
upper 95% Mean	0.025872
lower 95% Mean	0.0176063
N	46
Sum Wgt	46
Sum	1
Variance	0.0001937
Skewness	1.552819
Kurtosis	2.4554761
CV	64.018484
N Missing	0

Mean	3.2078261
Std Dev	0.4992916
Std Err Mean	0.0736165
upper 95% Mean	3.3560974
lower 95% Mean	3.0595548
N	46
Sum Wgt	46
Sum	147.56
Variance	0.2492921
Skewness	-0.278575
Kurtosis	0.2058587
CV	15.564796
N Missing	0

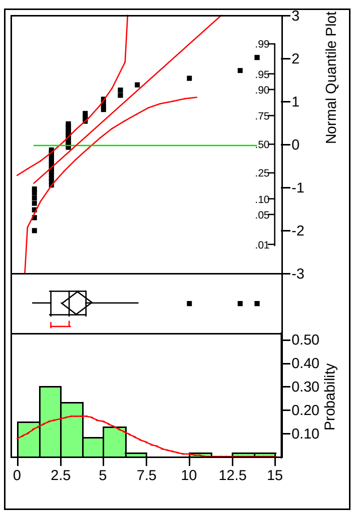
Relative Length

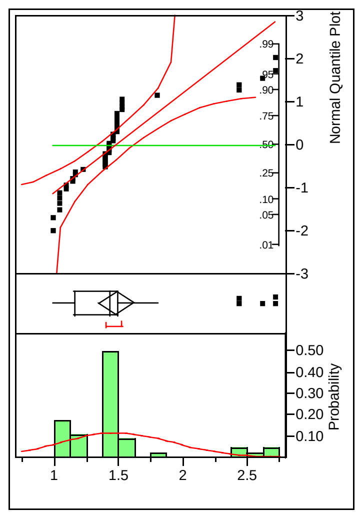




Mean Depth

Connectivity





Integration

Mean	3.4782609
Std Dev	2.8106079
Std Err Mean	0.4144015
upper 95% Mean	4.3129084
lower 95% Mean	2.6436133
N	46
Sum Wgt	46
Sum	160
Variance	7.8995169
Skewness	2.3469741
Kurtosis	6.0968104
CV	80.804978
N Missing	0

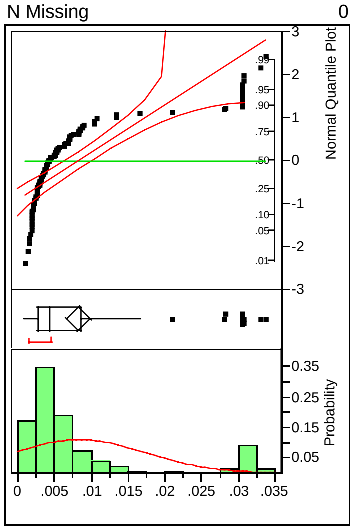
Mean	1.4892391
Std Dev	0.4320719
Std Err Mean	0.0637055
upper 95% Mean	1.6175486
lower 95% Mean	1.3609296
N	46
Sum Wgt	46
Sum	68.505
Variance	0.1866861
Skewness	1.7602026
Kurtosis	2.8661193
CV	29.012927
N Missing	0

25) L25: hoffmann

Figure 6.2 continued: (L25).

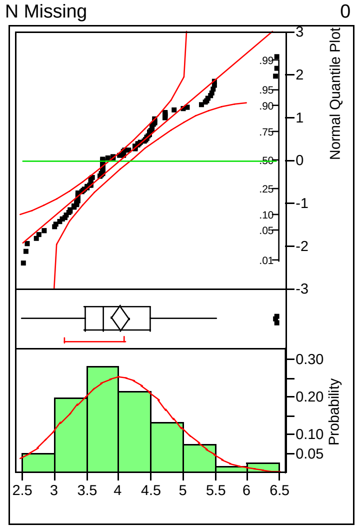
Relative Length

Mean	0.0083333
Std Dev	0.0091017
Std Err Mean	0.0008309
upper 95% Mean	0.0099785
lower 95% Mean	0.0066881
N	120
Sum Wgt	120
Sum	1
Variance	0.0000828
Skewness	1.8459042
Kurtosis	2.014664
CV	109.22053
N Missing	0

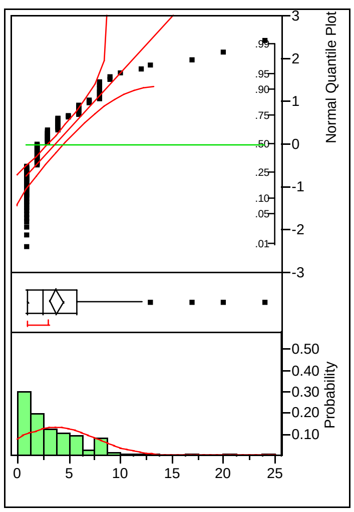


Mean Depth

Mean	4.04385
Std Dev	0.786915
Std Err Mean	0.0718352
upper 95% Mean	4.1860908
lower 95% Mean	3.9016092
N	120
Sum Wgt	120
Sum	485.262
Variance	0.6192352
Skewness	0.7764326
Kurtosis	0.8683334
CV	19.459549
N Missing	0

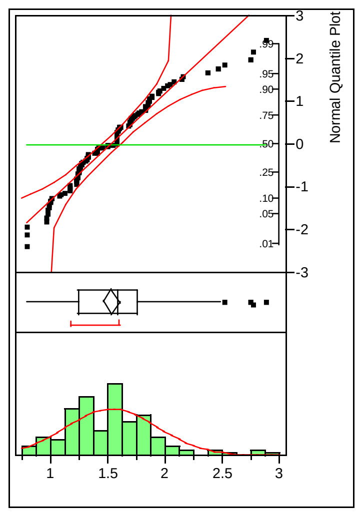


Connectivity



Mean	3.8333333
Std Dev	3.7936996
Std Err Mean	0.3463158
upper 95% Mean	4.5190732
lower 95% Mean	3.1475934
N	120
Sum Wgt	120
Sum	460
Variance	14.392157
Skewness	2.5782986
Kurtosis	9.0516186
CV	98.966077
N Missing	0

Integration



Mean	1.538475
Std Dev	0.400248
Std Err Mean	0.0365375
upper 95% Mean	1.6108229
lower 95% Mean	1.4661271
N	120
Sum Wgt	120
Sum	184.617
Variance	0.1601985
Skewness	0.8690828
Kurtosis	1.3474679
CV	26.015894
N Missing	0

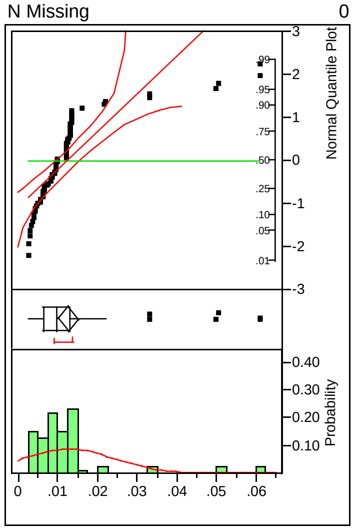
26) L26: ibm-cranford

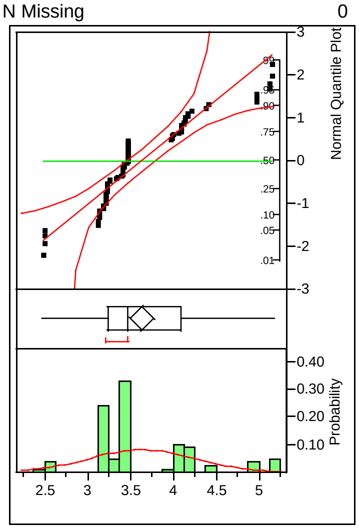
Figure 6.2 continued: (L26).

Mean	0.0128205
Std Dev	0.0114827
Std Err Mean	0.0013002
upper 95% Mean	0.0154095
lower 95% Mean	0.0102316
N	78
Sum Wgt	78
Sum	1
Variance	0.0001319
Skewness	2.9755692
Kurtosis	9.2742887
CV	89.56488
N Missing	0

Mean	3.6459359
Std Dev	0.6163753
Std Err Mean	0.0697908
upper 95% Mean	3.7849071
lower 95% Mean	3.5069647
N	78
Sum Wgt	78
Sum	284.383
Variance	0.3799185
Skewness	0.8977148
Kurtosis	0.7130437
CV	16.905818
N Missing	0

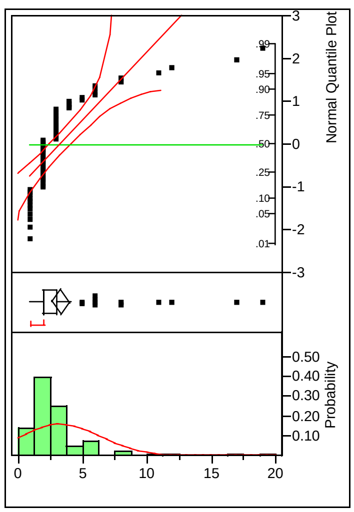
Relative Length

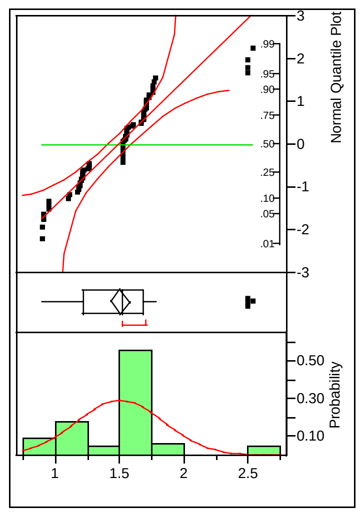




Mean Depth

Connectivity





Integration

Mean	3.3076923
Std Dev	3.1470774
Std Err Mean	0.3563363
upper 95% Mean	4.0172486
lower 95% Mean	2.598136
N	78
Sum Wgt	78
Sum	258
Variance	9.9040959
Skewness	3.2644302
Kurtosis	12.136508
CV	95.144199
N Missing	0

Mean	1.5095128
Std Dev	0.3410831
Std Err Mean	0.0386201
upper 95% Mean	1.5864152
lower 95% Mean	1.4326105
N	78
Sum Wgt	78
Sum	117.742
Variance	0.1163377
Skewness	0.7918215
Kurtosis	2.0913129
CV	22.595575
N Missing	0

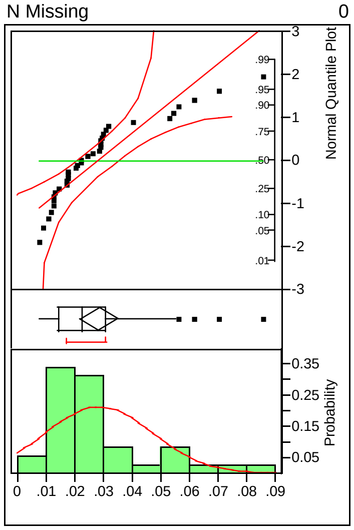
27) L27: ibm-london

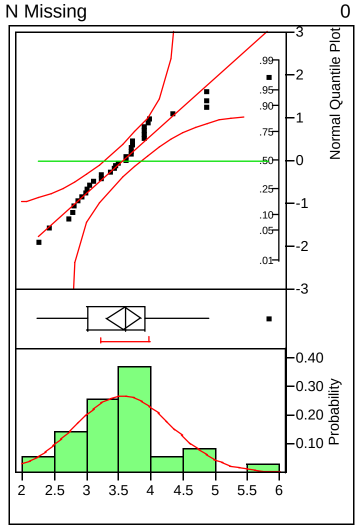
Figure 6.2 continued: (L27).

Mean	0.0285714
Std Dev	0.0186649
Std Err Mean	0.0031549
upper 95% Mean	0.0349831
lower 95% Mean	0.0221598
N	35
Sum Wgt	35
Sum	1
Variance	0.0003484
Skewness	1.4933424
Kurtosis	1.8743047
CV	65.327227
N Missing	0

Mean	3.5899143
Std Dev	0.7471543
Std Err Mean	0.1262921
upper 95% Mean	3.8465708
lower 95% Mean	3.3332578
N	35
Sum Wgt	35
Sum	125.647
Variance	0.5582395
Skewness	0.896414
Kurtosis	1.4389016
CV	20.812593
N Missing	0

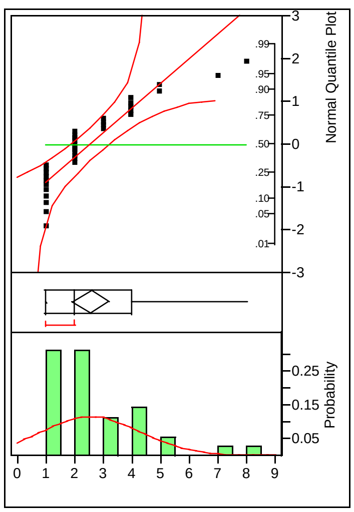
Relative Length

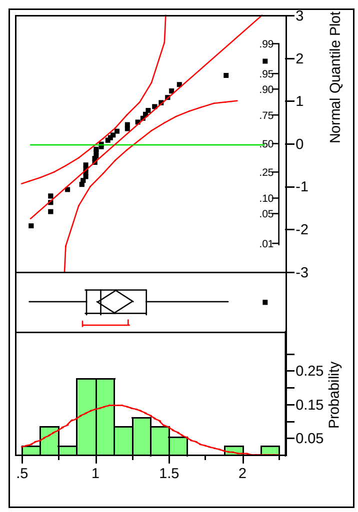




Mean Depth

Connectivity





Integration

Mean	2.5714286
Std Dev	1.7368957
Std Err Mean	0.293589
upper 95% Mean	3.1680731
lower 95% Mean	1.974784
N	35
Sum Wgt	35
Sum	90
Variance	3.0168067
Skewness	1.462312
Kurtosis	2.1600102
CV	67.545944
N Missing	0

Mean	1.1405429
Std Dev	0.3341517
Std Err Mean	0.0564819
upper 95% Mean	1.255328
lower 95% Mean	1.0257577
N	35
Sum Wgt	35
Sum	39.919
Variance	0.1116574
Skewness	1.0049637
Kurtosis	1.6242437
CV	29.297603
N Missing	0

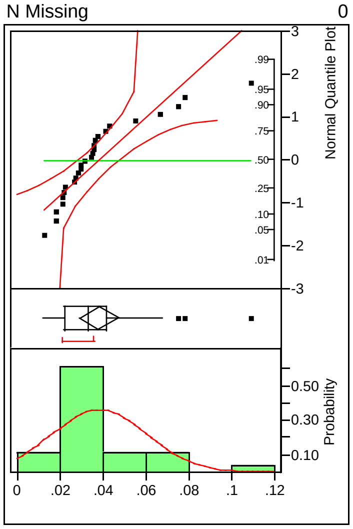
28) L28: ibm-melbourne

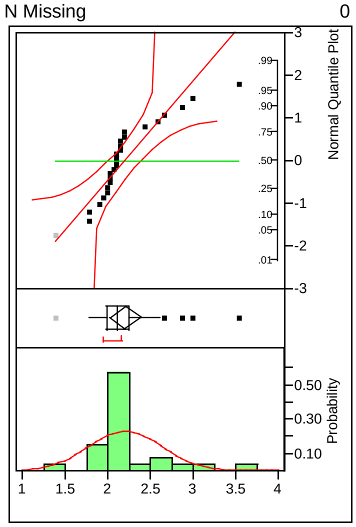
Figure 6.2 continued: (L28).

Mean	0.0384615
Std Dev	0.0221503
Std Err Mean	0.004344
upper 95% Mean	0.0474083
lower 95% Mean	0.0295148
N	26
Sum Wgt	26
Sum	1
Variance	0.0004906
Skewness	1.7685989
Kurtosis	3.2776675
CV	57.590906
N Missing	0

Mean	2.2153846
Std Dev	0.4331949
Std Err Mean	0.0849565
upper 95% Mean	2.3903558
lower 95% Mean	2.0404134
N	26
Sum Wgt	26
Sum	57.6
Variance	0.1876578
Skewness	1.3889542
Kurtosis	3.0100595
CV	19.553938
N Missing	0

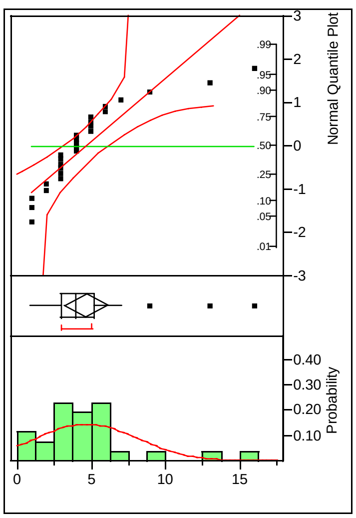
Relative Length

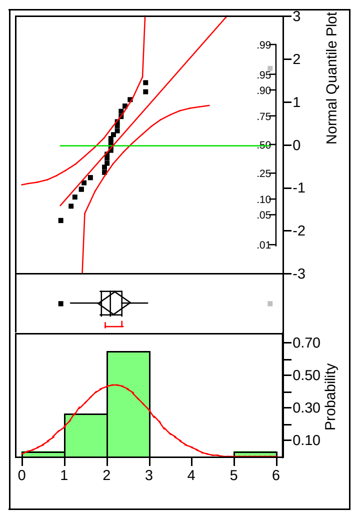




Mean Depth

Connectivity





Integration

Mean	4.6923077
Std Dev	3.4614359
Std Err Mean	0.6788434
upper 95% Mean	6.0904119
lower 95% Mean	3.2942035
N	26
Sum Wgt	26
Sum	122
Variance	11.981538
Skewness	1.9802533
Kurtosis	4.4713394
CV	73.768306
N Missing	0

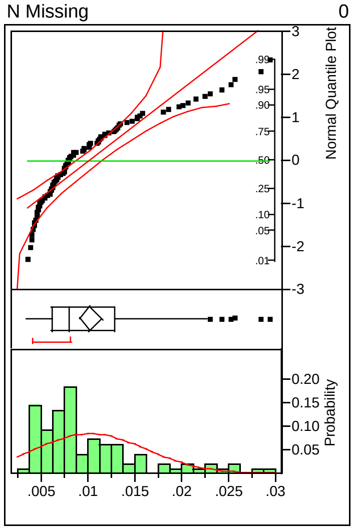
Mean	2.1794615
Std Dev	0.8986397
Std Err Mean	0.1762377
upper 95% Mean	2.54243
lower 95% Mean	1.8164931
N	26
Sum Wgt	26
Sum	56.666
Variance	0.8075533
Skewness	2.7890462
Kurtosis	11.643981
CV	41.232189
N Missing	0

29) L29: interpolis

Figure 6.2 continued: (L29).

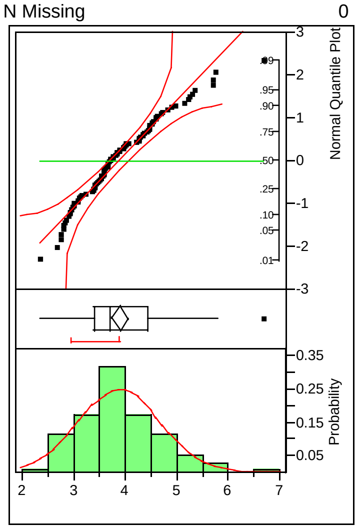
Relative Length

Mean	0.0103093
Std Dev	0.0059773
Std Err Mean	0.0006069
upper 95% Mean	0.011514
lower 95% Mean	0.0091046
N	97
Sum Wgt	97
Sum	1
Variance	0.0000357
Skewness	1.4240121
Kurtosis	1.4949764
CV	57.979346
N Missing	0

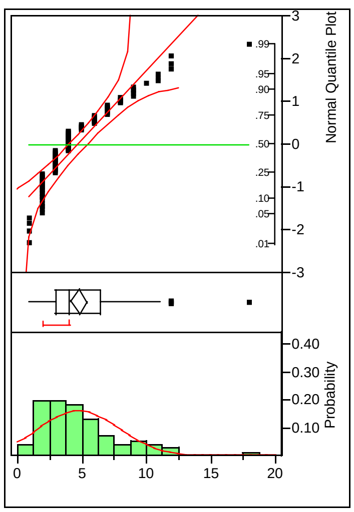


Mean Depth

Mean	3.9087938
Std Dev	0.800966
Std Err Mean	0.0813258
upper 95% Mean	4.0702242
lower 95% Mean	3.7473634
N	97
Sum Wgt	97
Sum	379.153
Variance	0.6415466
Skewness	0.7836261
Kurtosis	0.7496426
CV	20.491386
N Missing	0

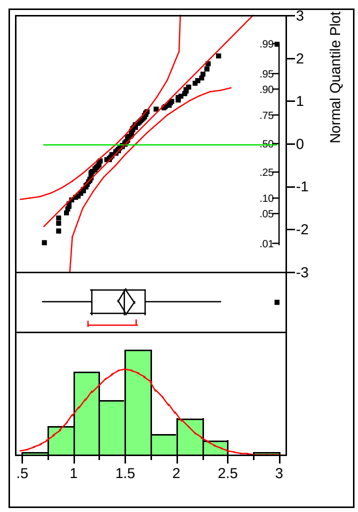


Connectivity



Mean	4.8041237
Std Dev	3.1045638
Std Err Mean	0.3152207
upper 95% Mean	5.4298318
lower 95% Mean	4.1784156
N	97
Sum Wgt	97
Sum	466
Variance	9.6383162
Skewness	1.4557161
Kurtosis	2.6191387
CV	64.622894
N Missing	0

Integration



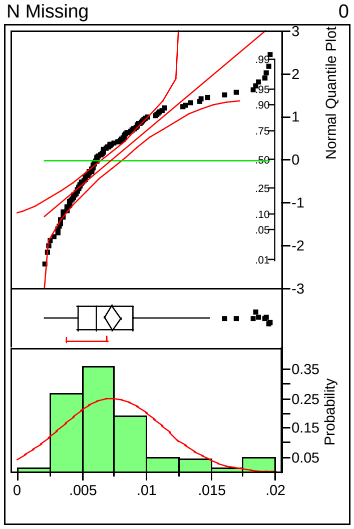
Mean	1.514
Std Dev	0.4124849
Std Err Mean	0.0418815
upper 95% Mean	1.5971341
lower 95% Mean	1.4308659
N	97
Sum Wgt	97
Sum	146.858
Variance	0.1701438
Skewness	0.7025682
Kurtosis	0.6590975
CV	27.244711
N Missing	0

30) L30: kew

Figure 6.2 continued: (L30).

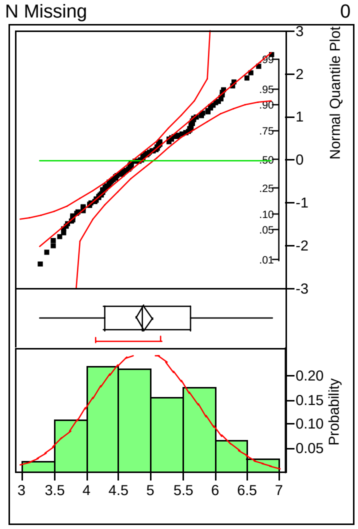
Relative Length

Mean	0.0074074
Std Dev	0.0039706
Std Err Mean	0.0003417
upper 95% Mean	0.0080833
lower 95% Mean	0.0067315
N	135
Sum Wgt	135
Sum	1
Variance	0.0000158
Skewness	1.5347411
Kurtosis	2.1061668
CV	53.602662
N Missing	0

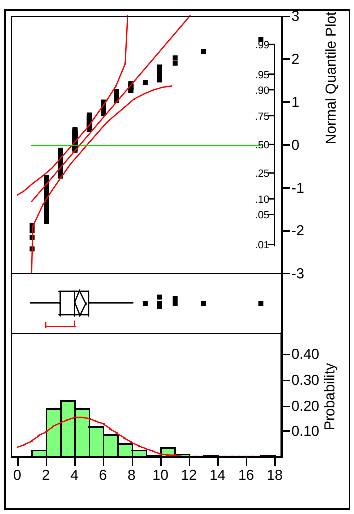


Mean Depth

Mean	4.9068074
Std Dev	0.7921274
Std Err Mean	0.0681755
upper 95% Mean	5.0416466
lower 95% Mean	4.7719682
N	135
Sum Wgt	135
Sum	662.419
Variance	0.6274658
Skewness	0.1963241
Kurtosis	-0.65733
CV	16.143437
N Missing	0

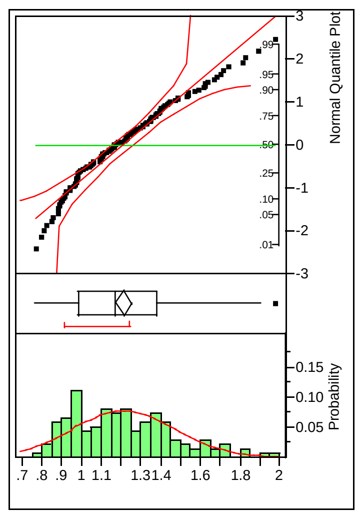


Connectivity



Mean	4.4
Std Dev	2.5806397
Std Err Mean	0.2221061
upper 95% Mean	4.8392872
lower 95% Mean	3.9607128
N	135
Sum Wgt	135
Sum	594
Variance	6.6597015
Skewness	1.740304
Kurtosis	4.3962419
CV	58.650903
N Missing	0

Integration



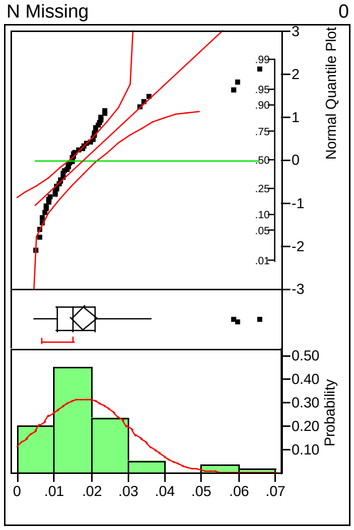
Mean	1.2160519
Std Dev	0.2572256
Std Err Mean	0.0221385
upper 95% Mean	1.2598379
lower 95% Mean	1.1722658
N	135
Sum Wgt	135
Sum	164.167
Variance	0.066165
Skewness	0.6415937
Kurtosis	-0.037368
CV	21.152518
N Missing	0

31) L31: kodak

Figure 6.2 continued: (L31).

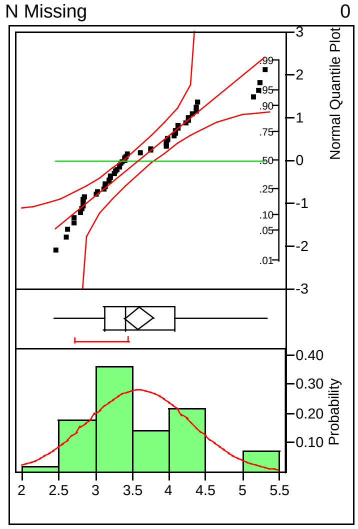
Relative Length

Mean	0.0181818
Std Dev	0.0126178
Std Err Mean	0.0017014
upper 95% Mean	0.0215929
lower 95% Mean	0.0147708
N	55
Sum Wgt	55
Sum	1
Variance	0.0001592
Skewness	2.3441295
Kurtosis	6.1233591
CV	69.397689
N Missing	0

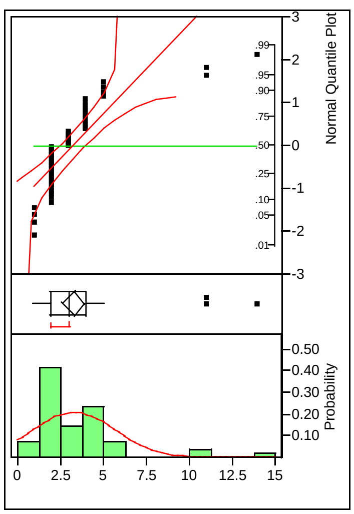


Mean Depth

Mean	3.5992727
Std Dev	0.7113781
Std Err Mean	0.0959222
upper 95% Mean	3.7915852
lower 95% Mean	3.4069603
N	55
Sum Wgt	55
Sum	197.96
Variance	0.5060588
Skewness	0.6667861
Kurtosis	-0.074632
CV	19.764495
N Missing	0

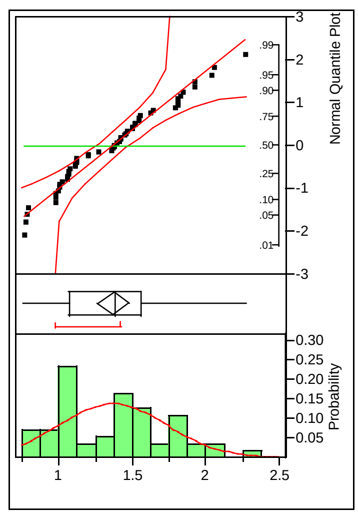


Connectivity



Mean	3.3090909
Std Dev	2.4027201
Std Err Mean	0.3239827
upper 95% Mean	3.9586371
lower 95% Mean	2.6595447
N	55
Sum Wgt	55
Sum	182
Variance	5.773064
Skewness	2.8460856
Kurtosis	9.4176598
CV	72.609674
N Missing	0

Integration



Mean	1.3731636
Std Dev	0.3627573
Std Err Mean	0.0489142
upper 95% Mean	1.4712307
lower 95% Mean	1.2750966
N	55
Sum Wgt	55
Sum	75.524
Variance	0.1315928
Skewness	0.3710304
Kurtosis	-0.527457
CV	26.417629
N Missing	0

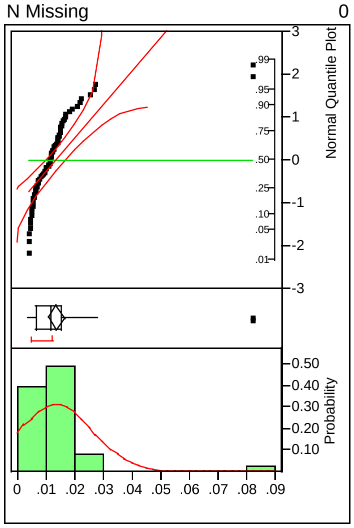
32) L32: lend

Figure 6.2 continued: (L32).

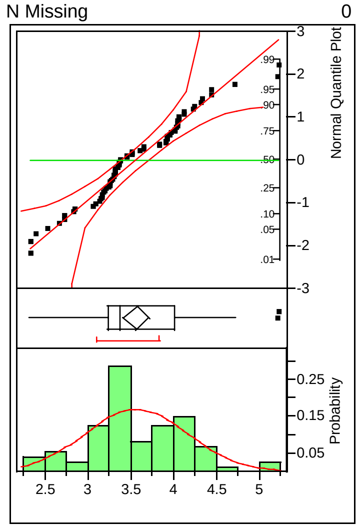
Mean	0.0136986
Std Dev	0.0128784
Std Err Mean	0.0015073
upper 95% Mean	0.0167034
lower 95% Mean	0.0106939
N	73
Sum Wgt	73
Sum	1
Variance	0.0001659
Skewness	4.3245044
Kurtosis	21.523834
CV	94.011971
N Missing	0

Mean	3.5760822
Std Dev	0.5944019
Std Err Mean	0.0695695
upper 95% Mean	3.7147664
lower 95% Mean	3.437398
N	73
Sum Wgt	73
Sum	261.054
Variance	0.3533136
Skewness	0.3388
Kurtosis	0.4801796
CV	16.621595
N Missing	0

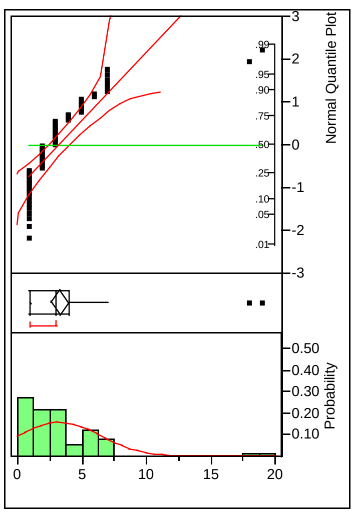
Relative Length



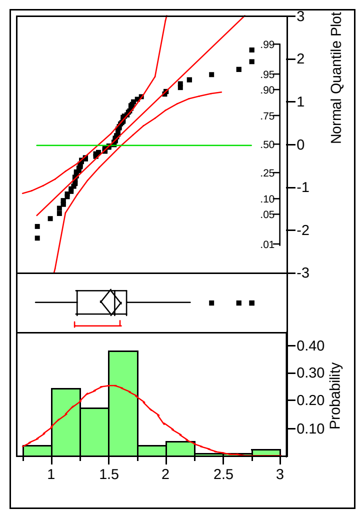
Mean Depth



Connectivity



Integration



Mean	3.3150685
Std Dev	3.1529383
Std Err Mean	0.3690235
upper 95% Mean	4.0507034
lower 95% Mean	2.5794336
N	73
Sum Wgt	73
Sum	242
Variance	9.9410198
Skewness	3.2412358
Kurtosis	13.508938
CV	95.109295
N Missing	0

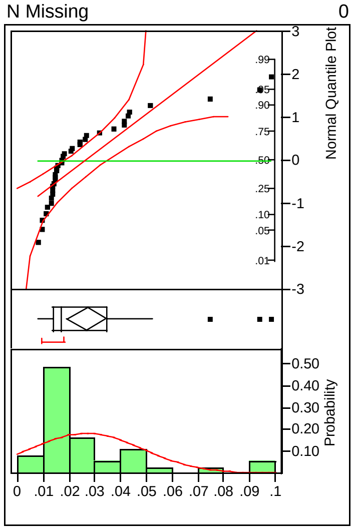
Mean	1.5229863
Std Dev	0.3902897
Std Err Mean	0.04568
upper 95% Mean	1.6140476
lower 95% Mean	1.431925
N	73
Sum Wgt	73
Sum	111.178
Variance	0.152326
Skewness	1.2734016
Kurtosis	2.1616233
CV	25.626605
N Missing	0

33) L33: leo

Figure 6.2 continued: (L33).

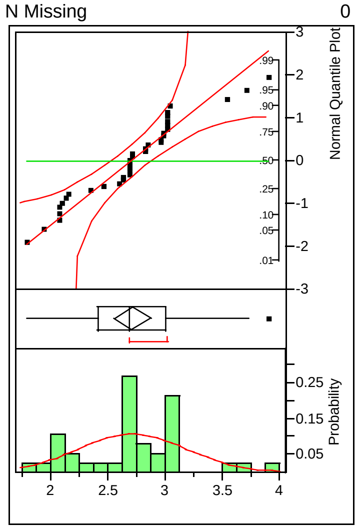
Relative Length

Mean	0.027027
Std Dev	0.0219713
Std Err Mean	0.0036121
upper 95% Mean	0.0343526
lower 95% Mean	0.0197014
N	37
Sum Wgt	37
Sum	1
Variance	0.0004827
Skewness	2.0996521
Kurtosis	4.2178285
CV	81.293666
N Missing	0

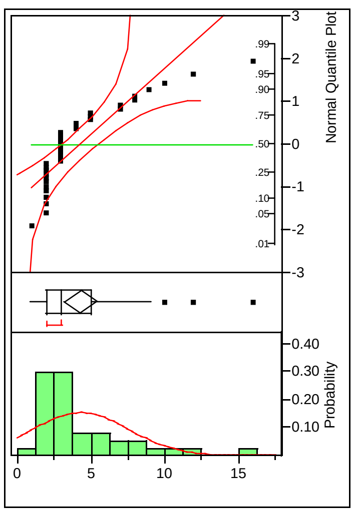


Mean Depth

Mean	2.7191351
Std Dev	0.4696543
Std Err Mean	0.0772107
upper 95% Mean	2.8757257
lower 95% Mean	2.5625446
N	37
Sum Wgt	37
Sum	100.608
Variance	0.2205752
Skewness	0.2636872
Kurtosis	0.4776206
CV	17.272195
N Missing	0

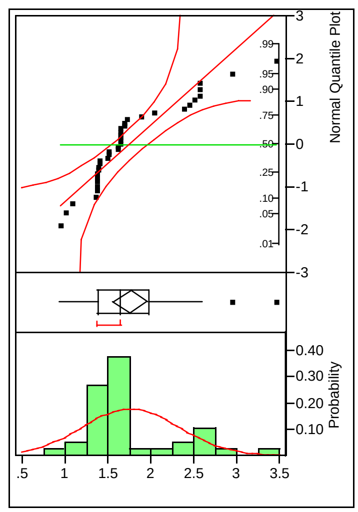


Connectivity



Mean	4.3243243
Std Dev	3.257931
Std Err Mean	0.5356005
upper 95% Mean	5.4105726
lower 95% Mean	3.2380761
N	37
Sum Wgt	37
Sum	160
Variance	10.614114
Skewness	1.9250801
Kurtosis	3.8746019
CV	75.339653
N Missing	0

Integration



Mean	1.7695946
Std Dev	0.560653
Std Err Mean	0.0921708
upper 95% Mean	1.9565256
lower 95% Mean	1.5826636
N	37
Sum Wgt	37
Sum	65.475
Variance	0.3143317
Skewness	1.2609719
Kurtosis	1.3289226
CV	31.682565
N Missing	0

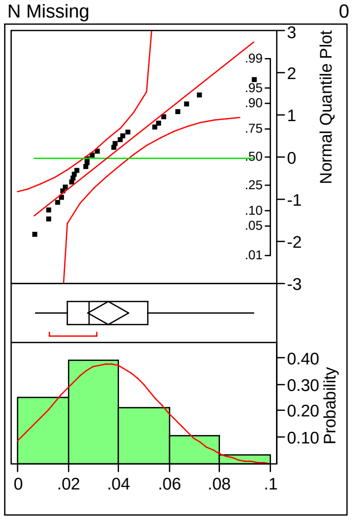
34) L34: lowe

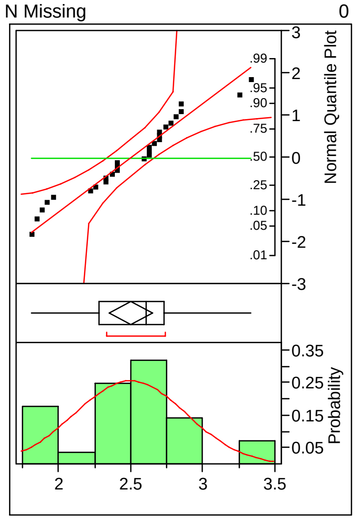
Figure 6.2 continued: (L34).

Mean	0.0357143
Std Dev	0.0210674
Std Err Mean	0.0039814
upper 95% Mean	0.0438834
lower 95% Mean	0.0275452
N	28
Sum Wgt	28
Sum	1
Variance	0.0004438
Skewness	0.9919955
Kurtosis	0.5741841
CV	58.988798
N Missing	0

Mean	2.5026786
Std Dev	0.3886605
Std Err Mean	0.0734499
upper 95% Mean	2.6533854
lower 95% Mean	2.3519718
N	28
Sum Wgt	28
Sum	70.075
Variance	0.151057
Skewness	-0.027873
Kurtosis	-0.101283
CV	15.52978
N Missing	0

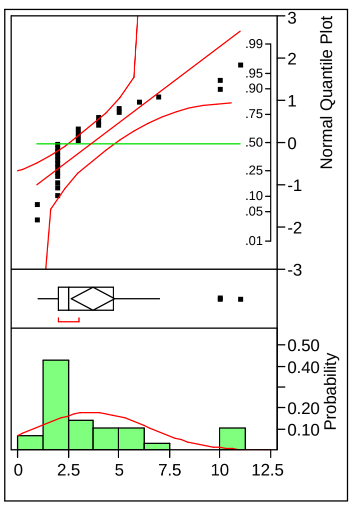
Relative Length

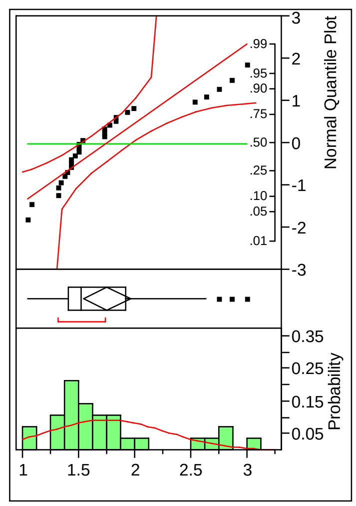




Mean Depth

Connectivity





Integration

Mean	3.7142857
Std Dev	2.7468115
Std Err Mean	0.5190986
upper 95% Mean	4.779388
lower 95% Mean	2.6491834
N	28
Sum Wgt	28
Sum	104
Variance	7.5449735
Skewness	1.6036797
Kurtosis	1.7576865
CV	73.952618
N Missing	0

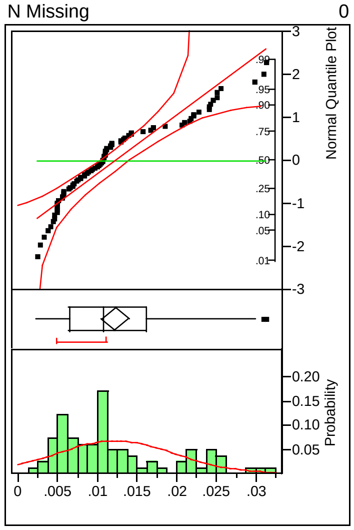
Mean	1.7539643
Std Dev	0.5338497
Std Err Mean	0.1008881
upper 95% Mean	1.9609696
lower 95% Mean	1.546959
N	28
Sum Wgt	28
Sum	49.111
Variance	0.2849955
Skewness	1.1433083
Kurtosis	0.3953092
CV	30.436749
N Missing	0

35) L35: mc-helsinki

Figure 6.2 continued: (L35).

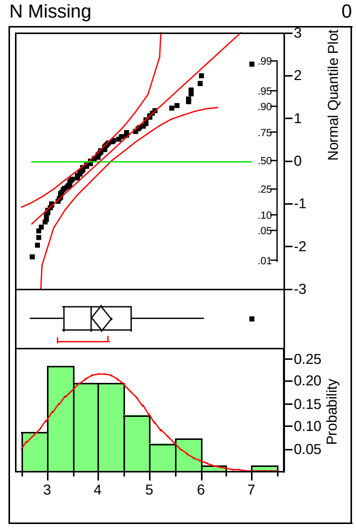
Relative Length

Mean	0.0123457
Std Dev	0.0073683
Std Err Mean	0.0008187
upper 95% Mean	0.0139749
lower 95% Mean	0.0107164
N	81
Sum Wgt	81
Sum	1
Variance	0.0000543
Skewness	0.9281886
Kurtosis	-0.068346
CV	59.683176
N Missing	0

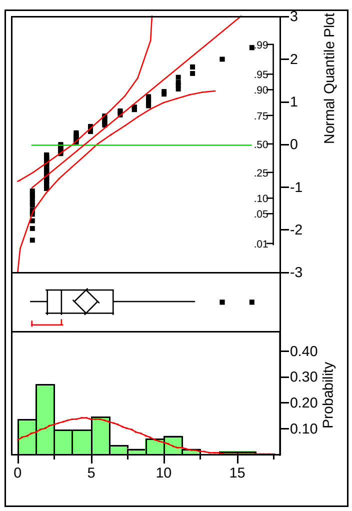


Mean Depth

Mean	4.0589753
Std Dev	0.9172952
Std Err Mean	0.1019217
upper 95% Mean	4.2618059
lower 95% Mean	3.8561447
N	81
Sum Wgt	81
Sum	328.777
Variance	0.8414304
Skewness	0.8546375
Kurtosis	0.3525459
CV	22.599181
N Missing	0

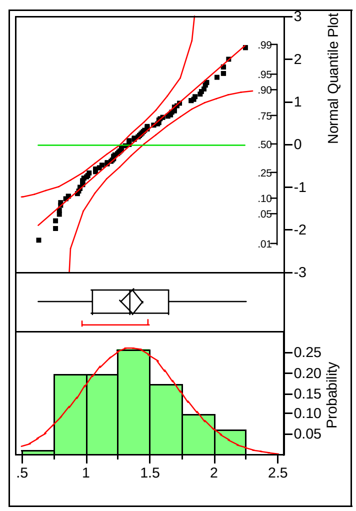


Connectivity



Mean	4.6666667
Std Dev	3.5637059
Std Err Mean	0.3959673
upper 95% Mean	5.4546668
lower 95% Mean	3.8786666
N	81
Sum Wgt	81
Sum	378
Variance	12.7
Skewness	1.108366
Kurtosis	0.4937139
CV	76.365127
N Missing	0

Integration



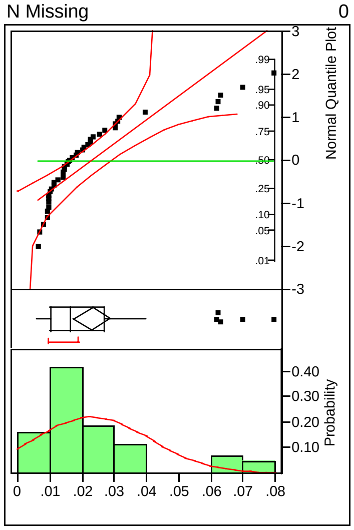
Mean	1.3655309
Std Dev	0.3800872
Std Err Mean	0.0422319
upper 95% Mean	1.449575
lower 95% Mean	1.2814867
N	81
Sum Wgt	81
Sum	110.608
Variance	0.1444663
Skewness	0.2676864
Kurtosis	-0.68895
CV	27.834388
N Missing	0

36) L36: mc-milan

Figure 6.2 continued: (L36).

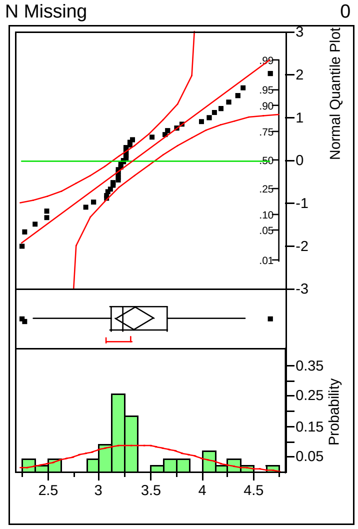
Relative Length

Mean	0.0232558
Std Dev	0.0181081
Std Err Mean	0.0027615
upper 95% Mean	0.0288287
lower 95% Mean	0.017683
N	43
Sum Wgt	43
Sum	1
Variance	0.0003279
Skewness	1.8240434
Kurtosis	2.6253515
CV	77.86469
N Missing	0

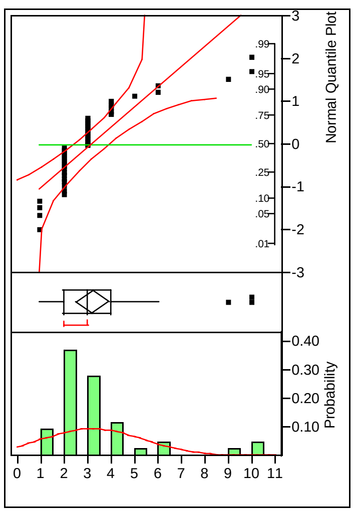


Mean Depth

Mean	3.3487907
Std Dev	0.5606273
Std Err Mean	0.0854949
upper 95% Mean	3.5213263
lower 95% Mean	3.1762551
N	43
Sum Wgt	43
Sum	143.998
Variance	0.314303
Skewness	0.3250739
Kurtosis	0.1309974
CV	16.741187
N Missing	0

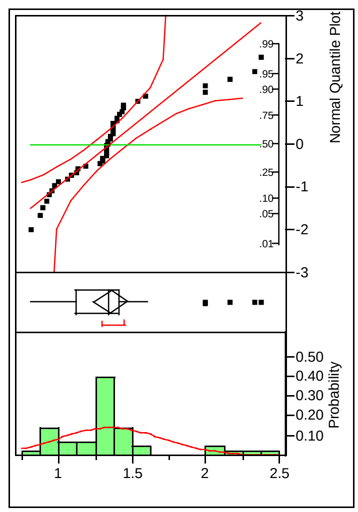


Connectivity



Mean	3.2093023
Std Dev	2.1331638
Std Err Mean	0.3253044
upper 95% Mean	3.8657932
lower 95% Mean	2.5528114
N	43
Sum Wgt	43
Sum	138
Variance	4.5503876
Skewness	2.0595847
Kurtosis	4.2555896
CV	66.468146
N Missing	0

Integration



Mean	1.3559767
Std Dev	0.3596612
Std Err Mean	0.0548478
upper 95% Mean	1.4666641
lower 95% Mean	1.2452893
N	43
Sum Wgt	43
Sum	58.307
Variance	0.1293562
Skewness	1.2599583
Kurtosis	1.8871018
CV	26.524146
N Missing	0

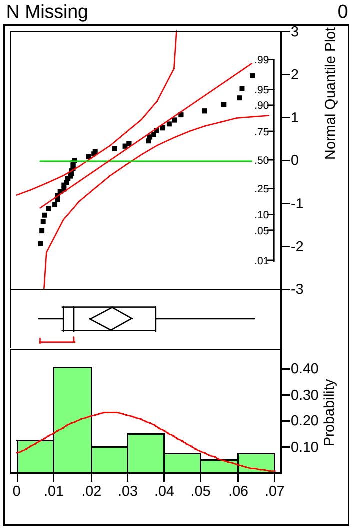
37) L37: mgic

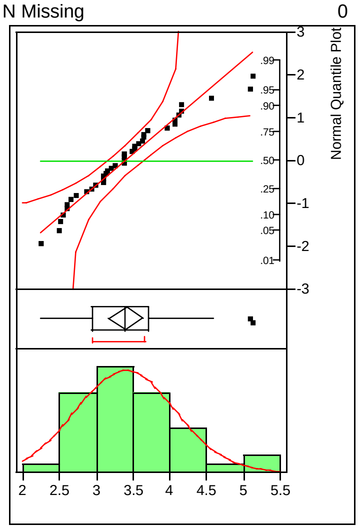
Figure 6.2 continued: (L37).

Mean	0.025641
Std Dev	0.0171878
Std Err Mean	0.0027523
upper 95% Mean	0.0312127
lower 95% Mean	0.0200694
N	39
Sum Wgt	39
Sum	1
Variance	0.0002954
Skewness	0.868198
Kurtosis	-0.418602
CV	67.03248
N Missing	0

Mean	3.413
Std Dev	0.6789465
Std Err Mean	0.1087185
upper 95% Mean	3.633089
lower 95% Mean	3.192911
N	39
Sum Wgt	39
Sum	133.107
Variance	0.4609684
Skewness	0.6795668
Kurtosis	0.427583
CV	19.892954
N Missing	0

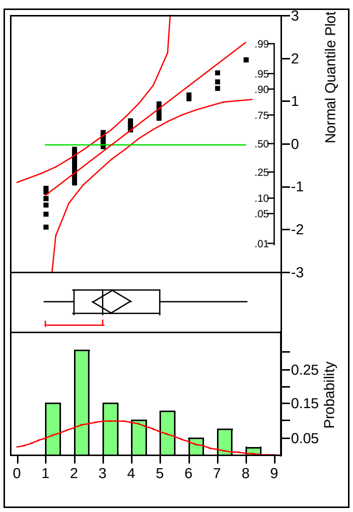
Relative Length

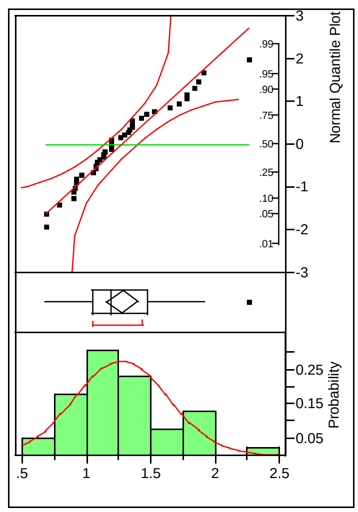




Mean Depth

Connectivity





Integration

Mean	3.3333333
Std Dev	1.964599
Std Err Mean	0.3145876
upper 95% Mean	3.9701826
lower 95% Mean	2.696484
N	39
Sum Wgt	39
Sum	130
Variance	3.8596491
Skewness	0.7568237
Kurtosis	-0.411872
CV	58.937969
N Missing	0

Mean	1.2841282
Std Dev	0.3636854
Std Err Mean	0.0582363
upper 95% Mean	1.4020214
lower 95% Mean	1.166235
N	39
Sum Wgt	39
Sum	50.081
Variance	0.1322671
Skewness	0.6925985
Kurtosis	0.1703179
CV	28.321579
N Missing	0

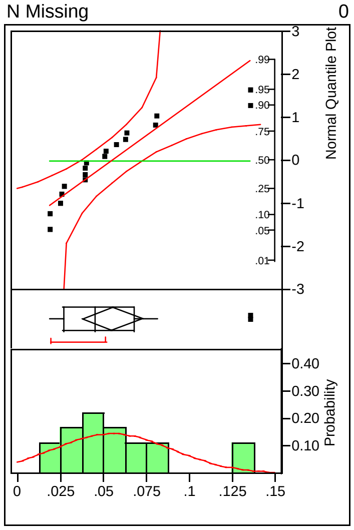
38) L38: nickelodeon

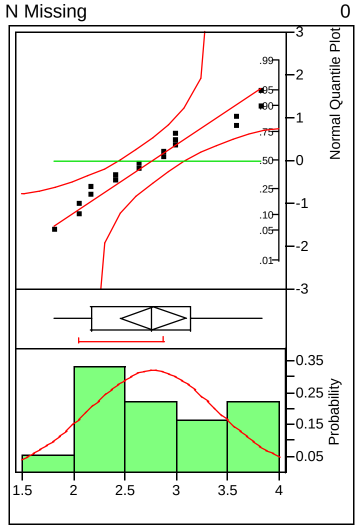
Figure 6.2 continued: (L38).

Mean	0.0555556
Std Dev	0.0347357
Std Err Mean	0.0081873
upper 95% Mean	0.0728292
lower 95% Mean	0.0382819
N	18
Sum Wgt	18
Sum	1
Variance	0.0012066
Skewness	1.3983981
Kurtosis	1.560401
CV	62.524221
N Missing	0

Mean	2.7777778
Std Dev	0.6250174
Std Err Mean	0.147318
upper 95% Mean	3.0885916
lower 95% Mean	2.4669639
N	18
Sum Wgt	18
Sum	50
Variance	0.3906468
Skewness	0.336287
Kurtosis	-0.906891
CV	22.500627
N Missing	0

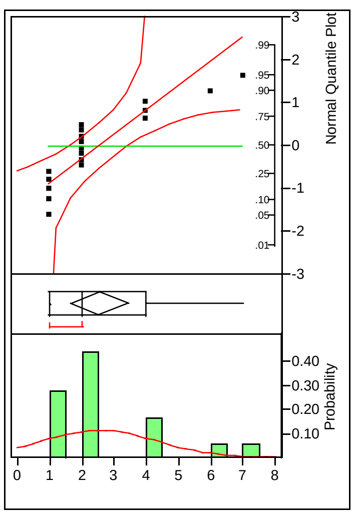
Relative Length

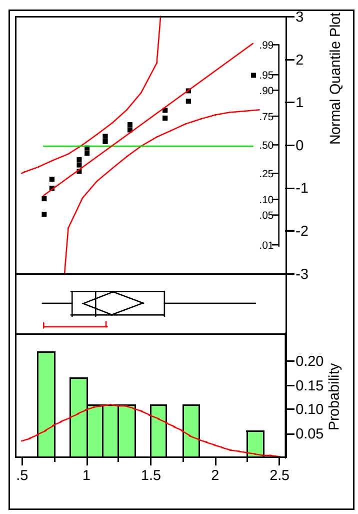




Mean Depth

Connectivity





Integration

Mean	2.5555556
Std Dev	1.7564075
Std Err Mean	0.4139892
upper 95% Mean	3.4289965
lower 95% Mean	1.6821147
N	18
Sum Wgt	18
Sum	46
Variance	3.0849673
Skewness	1.4351207
Kurtosis	1.443509
CV	68.728989
N Missing	0

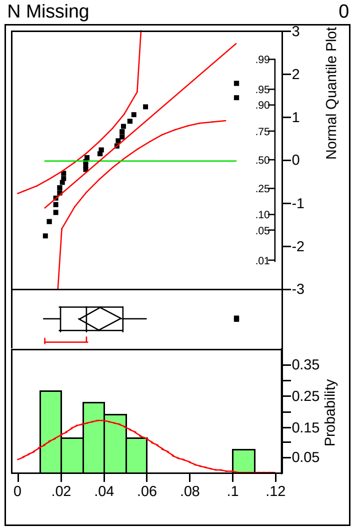
Mean	1.2101111
Std Dev	0.4580122
Std Err Mean	0.1079545
upper 95% Mean	1.4378752
lower 95% Mean	0.982347
N	18
Sum Wgt	18
Sum	21.782
Variance	0.2097752
Skewness	0.8575496
Kurtosis	0.2160758
CV	37.848771
N Missing	0

39) L39: olivetti-a

Figure 6.2 continued: (L39).

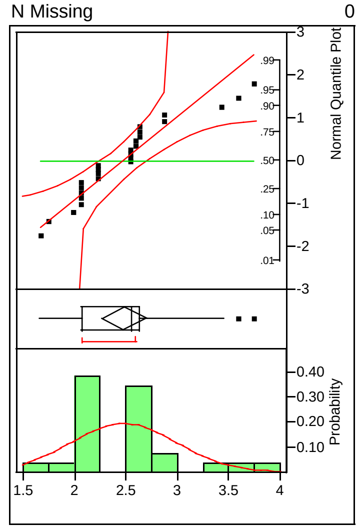
Relative Length

Mean	0.0384615
Std Dev	0.0234103
Std Err Mean	0.0045911
upper 95% Mean	0.0479172
lower 95% Mean	0.0290059
N	26
Sum Wgt	26
Sum	1
Variance	0.000548
Skewness	1.511669
Kurtosis	2.4877658
CV	60.866787
N Missing	0

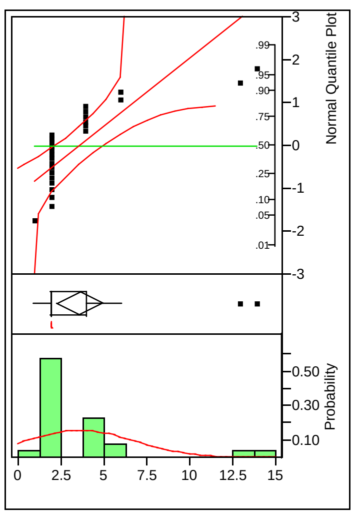


Mean Depth

Mean	2.4892308
Std Dev	0.5170139
Std Err Mean	0.1013948
upper 95% Mean	2.6980572
lower 95% Mean	2.2804043
N	26
Sum Wgt	26
Sum	64.72
Variance	0.2673034
Skewness	0.9332673
Kurtosis	0.8182465
CV	20.770027
N Missing	0

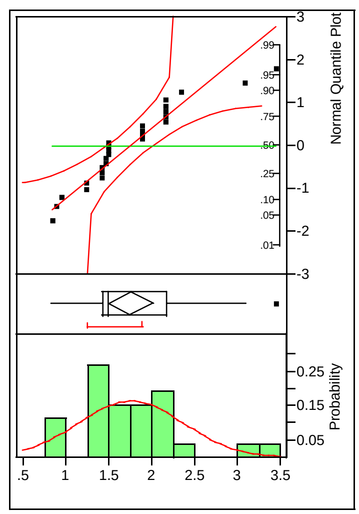


Connectivity



Mean	3.6153846
Std Dev	3.1884407
Std Err Mean	0.6253047
upper 95% Mean	4.9032237
lower 95% Mean	2.3275456
N	26
Sum Wgt	26
Sum	94
Variance	10.166154
Skewness	2.5303267
Kurtosis	6.2503252
CV	88.190912
N Missing	0

Integration



Mean	1.764
Std Dev	0.6134198
Std Err Mean	0.1203015
upper 95% Mean	2.0117656
lower 95% Mean	1.5162344
N	26
Sum Wgt	26
Sum	45.864
Variance	0.3762838
Skewness	1.008959
Kurtosis	1.4477673
CV	34.774365
N Missing	0

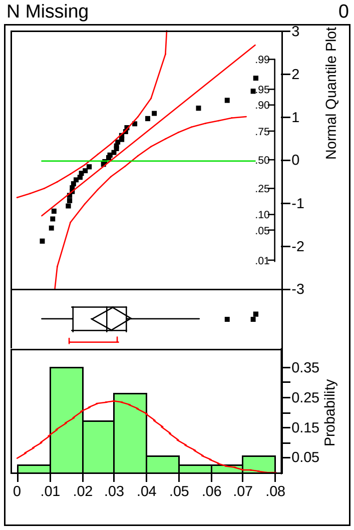
40) L40: olivetti-b

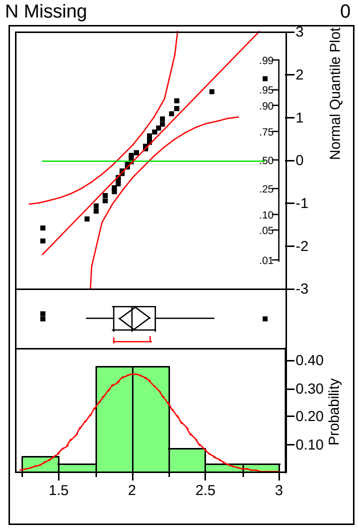
Figure 6.2 continued: (L40).

Mean	0.0294118
Std Dev	0.0167283
Std Err Mean	0.0028689
upper 95% Mean	0.0352486
lower 95% Mean	0.023575
N	34
Sum Wgt	34
Sum	1
Variance	0.0002798
Skewness	1.3744464
Kurtosis	1.6855916
CV	56.87632
N Missing	0

Mean	2.0178235
Std Dev	0.2834408
Std Err Mean	0.0486097
upper 95% Mean	2.1167207
lower 95% Mean	1.9189264
N	34
Sum Wgt	34
Sum	68.606
Variance	0.0803387
Skewness	0.5130043
Kurtosis	2.6585397
CV	14.046858
N Missing	0

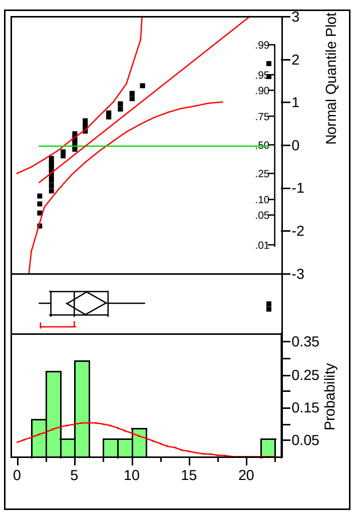
Relative Length

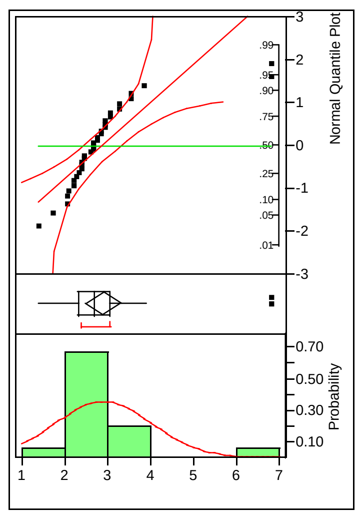




Mean Depth

Connectivity





Integration

Mean	6.0588235
Std Dev	4.7796359
Std Err Mean	0.8197008
upper 95% Mean	7.7265174
lower 95% Mean	4.3911297
N	34
Sum Wgt	34
Sum	206
Variance	22.84492
Skewness	2.3179596
Kurtosis	5.9237927
CV	78.887195
N Missing	0

Mean	2.9074118
Std Dev	1.1243034
Std Err Mean	0.1928164
upper 95% Mean	3.2996998
lower 95% Mean	2.5151238
N	34
Sum Wgt	34
Sum	98.852
Variance	1.2640582
Skewness	2.5984019
Kurtosis	7.8052414
CV	38.670251
N Missing	0

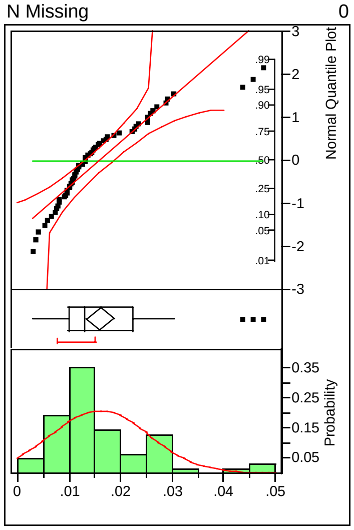
41) L41: olivetti-c

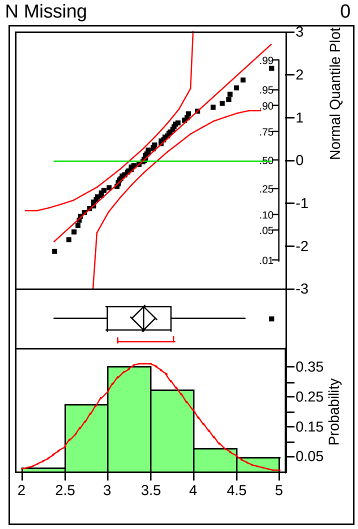
Figure 6.2 continued: (L41).

Mean	0.016129
Std Dev	0.0096232
Std Err Mean	0.0012222
upper 95% Mean	0.0185729
lower 95% Mean	0.0136852
N	62
Sum Wgt	62
Sum	1
Variance	0.0000926
Skewness	1.4966059
Kurtosis	2.4919529
CV	59.664012
N Missing	0

Mean	3.4283226
Std Dev	0.5475305
Std Err Mean	0.0695364
upper 95% Mean	3.5673693
lower 95% Mean	3.2892759
N	62
Sum Wgt	62
Sum	212.556
Variance	0.2997896
Skewness	0.4914129
Kurtosis	0.0262132
CV	15.970797
N Missing	0

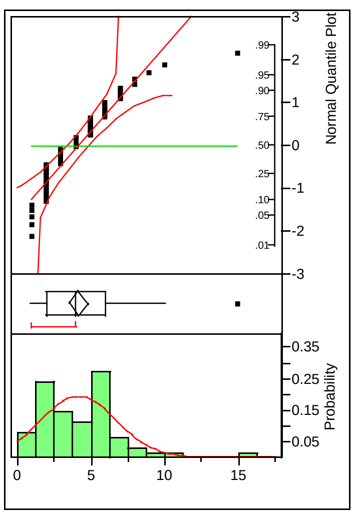
Relative Length

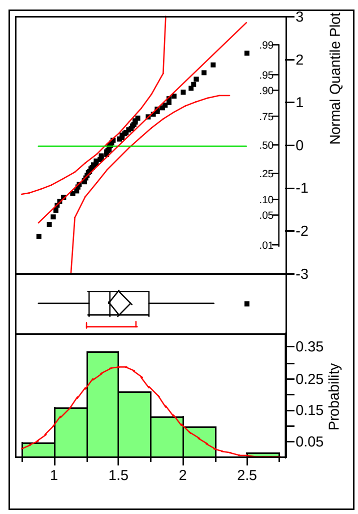




Mean Depth

Connectivity





Integration

Mean	4.1935484
Std Dev	2.5597048
Std Err Mean	0.3250828
upper 95% Mean	4.8435917
lower 95% Mean	3.5435051
N	62
Sum Wgt	62
Sum	260
Variance	6.5520888
Skewness	1.4923217
Kurtosis	3.9843174
CV	61.039115
N Missing	0

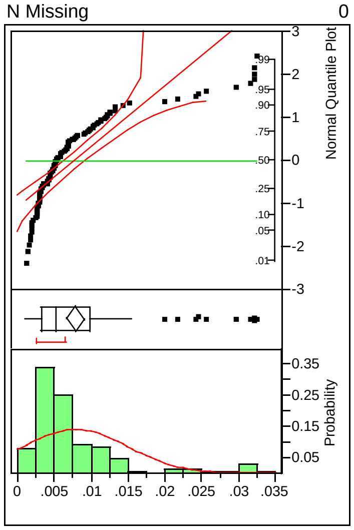
Mean	1.5097419
Std Dev	0.3450666
Std Err Mean	0.0438235
upper 95% Mean	1.5973725
lower 95% Mean	1.4221114
N	62
Sum Wgt	62
Sum	93.604
Variance	0.119071
Skewness	0.6106739
Kurtosis	0.1038772
CV	22.856001
N Missing	0

42) L42: orenstein

Figure 6.2 continued: (L42).

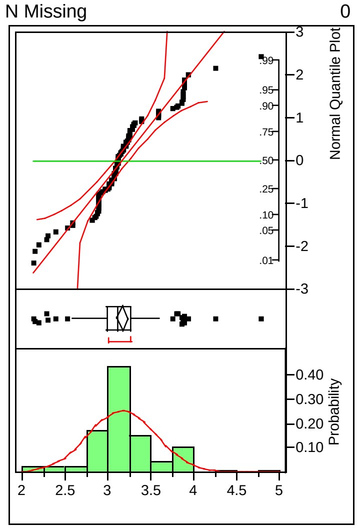
Relative Length

Mean	0.0079365
Std Dev	0.0071097
Std Err Mean	0.0006334
upper 95% Mean	0.00919
lower 95% Mean	0.006683
N	126
Sum Wgt	126
Sum	1
Variance	0.0000505
Skewness	2.1792561
Kurtosis	4.5034696
CV	89.581684
N Missing	0

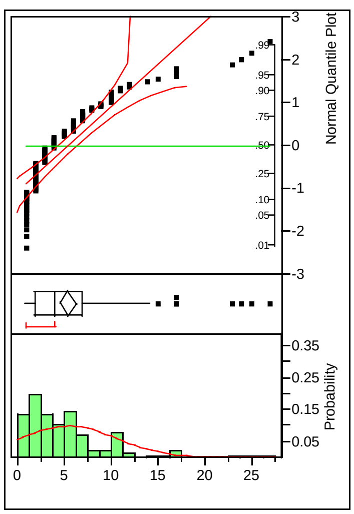


Mean Depth

Mean	3.1784127
Std Dev	0.3968649
Std Err Mean	0.0353555
upper 95% Mean	3.2483857
lower 95% Mean	3.1084397
N	126
Sum Wgt	126
Sum	400.48
Variance	0.1575017
Skewness	0.5539705
Kurtosis	2.5437123
CV	12.48626
N Missing	0

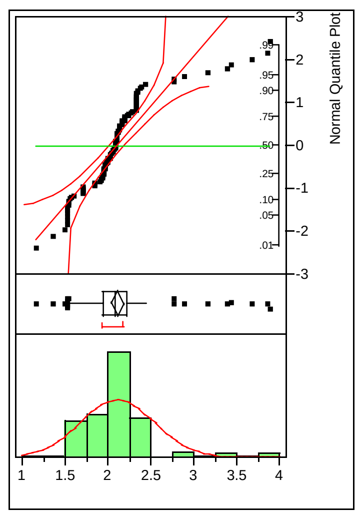


Connectivity



Mean	5.4761905
Std Dev	5.0781324
Std Err Mean	0.452396
upper 95% Mean	6.3715383
lower 95% Mean	4.5808427
N	126
Sum Wgt	126
Sum	690
Variance	25.787429
Skewness	2.1227346
Kurtosis	5.2446229
CV	92.731113
N Missing	0

Integration



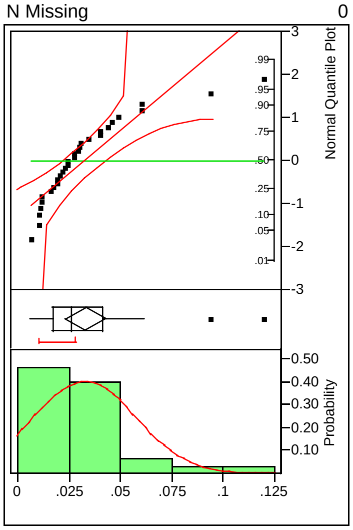
Mean	2.1191667
Std Dev	0.4310089
Std Err Mean	0.0383973
upper 95% Mean	2.1951597
lower 95% Mean	2.0431736
N	126
Sum Wgt	126
Sum	267.015
Variance	0.1857686
Skewness	1.7878241
Kurtosis	5.6558356
CV	20.338601
N Missing	0

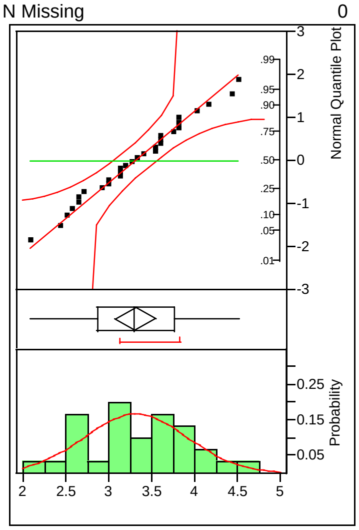
43) L43: sears-40

Figure 6.2 continued: (L43).

Mean	0.0333333	Mean	3.3218667
Std Dev	0.0248802	Std Dev	0.5997561
Std Err Mean	0.0045425	Std Err Mean	0.1095
upper 95% Mean	0.0426238	upper 95% Mean	3.5458193
lower 95% Mean	0.0240429	lower 95% Mean	3.097914
N	30	N	30
Sum Wgt	30	Sum Wgt	30
Sum	1	Sum	99.656
Variance	0.000619	Variance	0.3597074
Skewness	2.0333489	Skewness	0.0577548
Kurtosis	4.8540898	Kurtosis	-0.463472
CV	74.640701	CV	18.054793
N Missing	0	N Missing	0

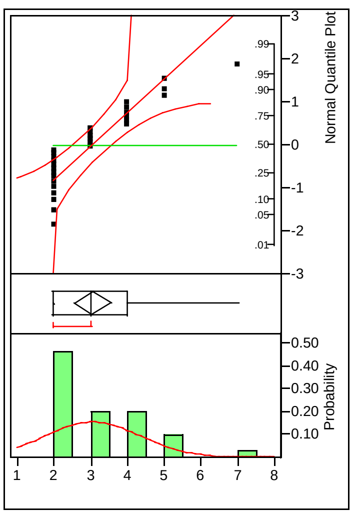
Relative Length

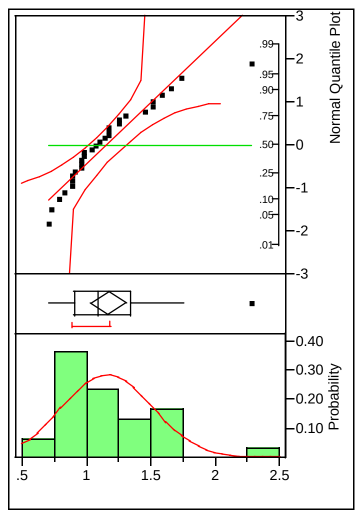




Mean Depth

Connectivity





Integration

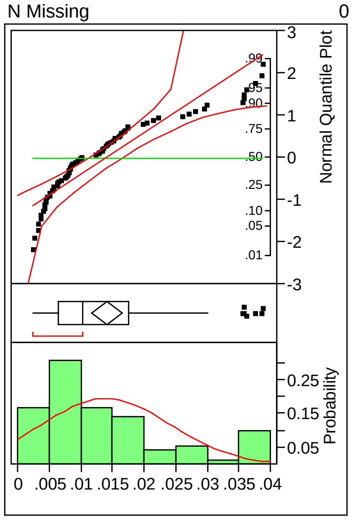
Mean	3.0666667	Mean	1.1735333
Std Dev	1.2847469	Std Dev	0.3506024
Std Err Mean	0.2345616	Std Err Mean	0.0640109
upper 95% Mean	3.5463991	upper 95% Mean	1.3044504
lower 95% Mean	2.5869343	lower 95% Mean	1.0426162
N	30	N	30
Sum Wgt	30	Sum Wgt	30
Sum	92	Sum	35.206
Variance	1.6505747	Variance	0.1229221
Skewness	1.2268593	Skewness	1.3094488
Kurtosis	1.3951658	Kurtosis	2.1839839
CV	41.893922	CV	29.875795
N Missing	0	N Missing	0

44) L44: sears-70

Figure 6.2 continued: (L44).

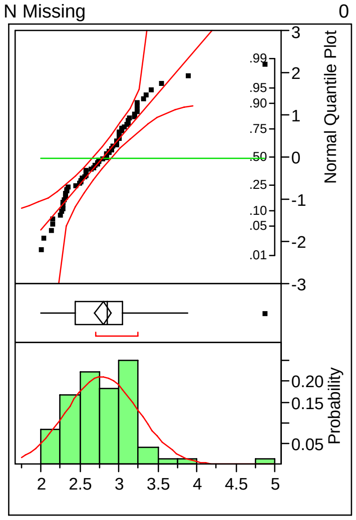
Relative Length

Mean	0.0140845
Std Dev	0.0101831
Std Err Mean	0.0012085
upper 95% Mean	0.0164948
lower 95% Mean	0.0116742
N	71
Sum Wgt	71
Sum	1
Variance	0.0001037
Skewness	1.121756
Kurtosis	0.3088373
CV	72.300156
N Missing	0

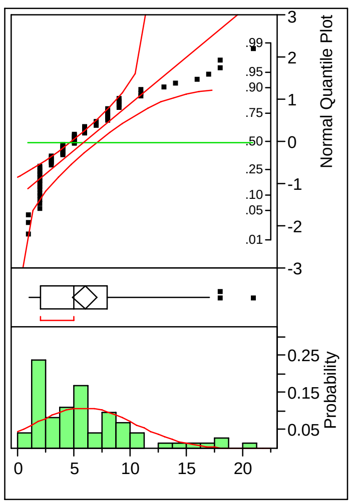


Mean Depth

Mean	2.7959718
Std Dev	0.4670362
Std Err Mean	0.055427
upper 95% Mean	2.9065175
lower 95% Mean	2.6854262
N	71
Sum Wgt	71
Sum	198.514
Variance	0.2181229
Skewness	1.2305773
Kurtosis	4.3543741
CV	16.703897
N Missing	0

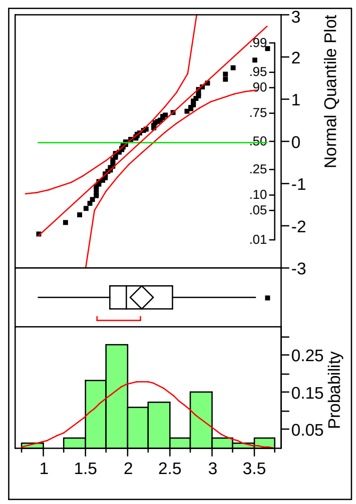


Connectivity



Mean	5.971831
Std Dev	4.5323341
Std Err Mean	0.5378891
upper 95% Mean	7.044617
lower 95% Mean	4.899045
N	71
Sum Wgt	71
Sum	424
Variance	20.542052
Skewness	1.4227986
Kurtosis	1.7906285
CV	75.895217
N Missing	0

Integration



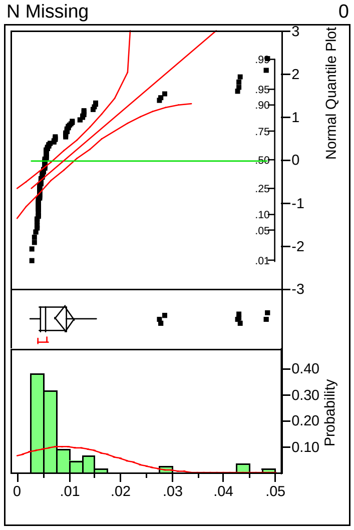
Mean	2.1746901
Std Dev	0.5481209
Std Err Mean	0.06505
upper 95% Mean	2.3044282
lower 95% Mean	2.044952
N	71
Sum Wgt	71
Sum	154.403
Variance	0.3004365
Skewness	0.6234424
Kurtosis	0.0263495
CV	25.204552
N Missing	0

45) L45: steelcase

Figure 6.2 continued: (L45).

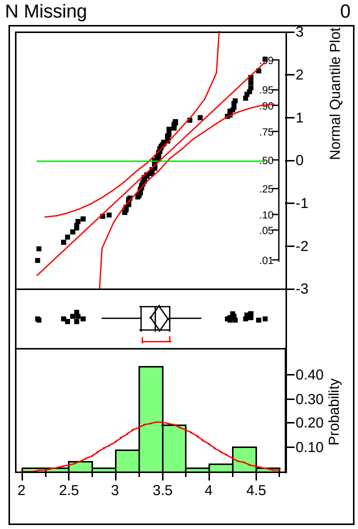
Relative Length

Mean	0.0092593
Std Dev	0.0098535
Std Err Mean	0.0009482
upper 95% Mean	0.0111389
lower 95% Mean	0.0073797
N	108
Sum Wgt	108
Sum	1
Variance	0.0000971
Skewness	2.8857513
Kurtosis	7.8067873
CV	106.4176
N Missing	0

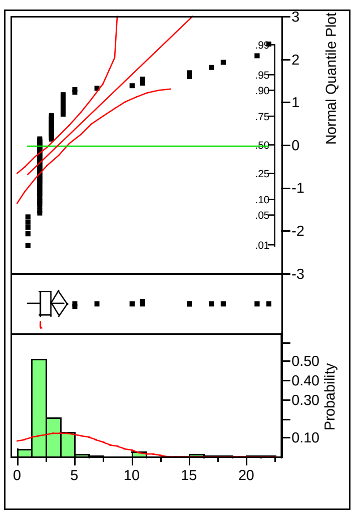


Mean Depth

Mean	3.4749259
Std Dev	0.4881359
Std Err Mean	0.0469709
upper 95% Mean	3.5680403
lower 95% Mean	3.3818116
N	108
Sum Wgt	108
Sum	375.292
Variance	0.2382767
Skewness	0.1246774
Kurtosis	0.7878279
CV	14.047377
N Missing	0

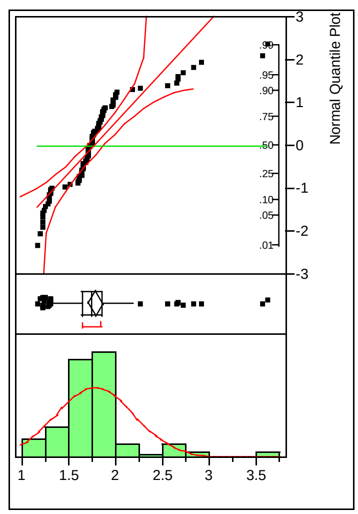


Connectivity



Mean	3.6481481
Std Dev	3.9133484
Std Err Mean	0.3765621
upper 95% Mean	4.3946386
lower 95% Mean	2.9016577
N	108
Sum Wgt	108
Sum	394
Variance	15.314296
Skewness	3.2438972
Kurtosis	10.391241
CV	107.26945
N Missing	0

Integration



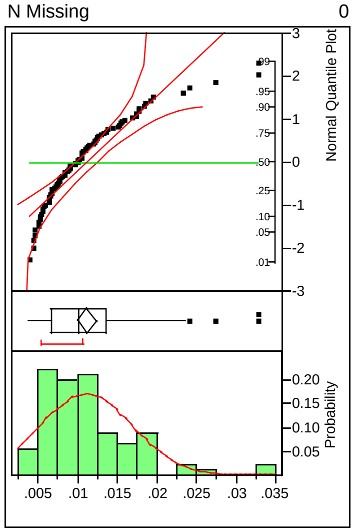
Mean	1.7919167
Std Dev	0.4213385
Std Err Mean	0.0405433
upper 95% Mean	1.8722891
lower 95% Mean	1.7115443
N	108
Sum Wgt	108
Sum	193.527
Variance	0.1775261
Skewness	1.9736704
Kurtosis	5.9813885
CV	23.513287
N Missing	0

46) L46: stockley-5

Figure 6.2 continued: (L46).

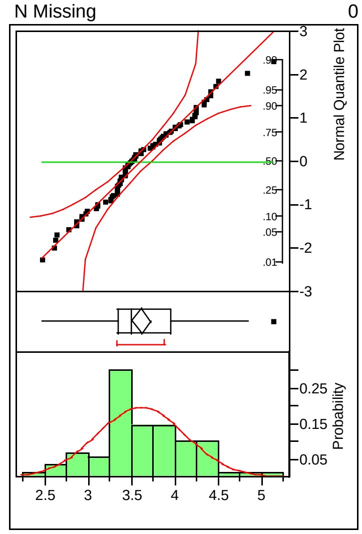
Relative Length

Mean	0.011236
Std Dev	0.0058355
Std Err Mean	0.0006186
upper 95% Mean	0.0124652
lower 95% Mean	0.0100067
N	89
Sum Wgt	89
Sum	1
Variance	0.0000341
Skewness	1.6336095
Kurtosis	3.3770122
CV	51.935948
N Missing	0

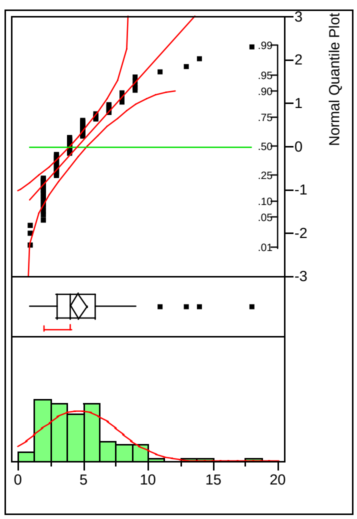


Mean Depth

Mean	3.6222921
Std Dev	0.5108642
Std Err Mean	0.0541515
upper 95% Mean	3.7299069
lower 95% Mean	3.5146774
N	89
Sum Wgt	89
Sum	322.384
Variance	0.2609823
Skewness	0.3071253
Kurtosis	0.1810633
CV	14.103341
N Missing	0

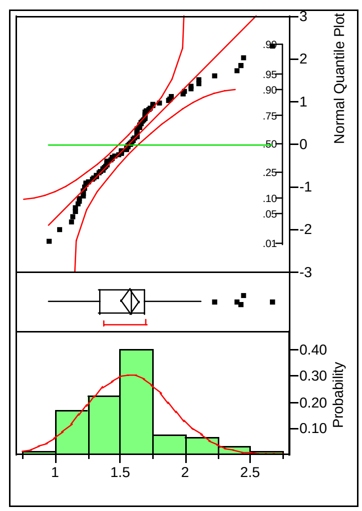


Connectivity



Mean	4.6966292
Std Dev	2.9901524
Std Err Mean	0.3169555
upper 95% Mean	5.3265117
lower 95% Mean	4.0667467
N	89
Sum Wgt	89
Sum	418
Variance	8.9410112
Skewness	1.7616978
Kurtosis	4.396269
CV	63.665924
N Missing	0

Integration



Mean	1.577618
Std Dev	0.3258006
Std Err Mean	0.0345348
upper 95% Mean	1.6462486
lower 95% Mean	1.5089873
N	89
Sum Wgt	89
Sum	140.408
Variance	0.106146
Skewness	0.9491112
Kurtosis	1.3499787
CV	20.651424
N Missing	0

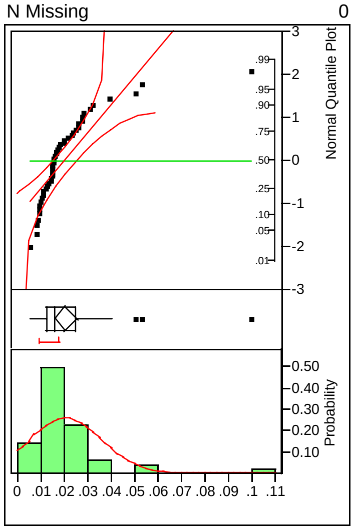
47) L47: stockley-sq

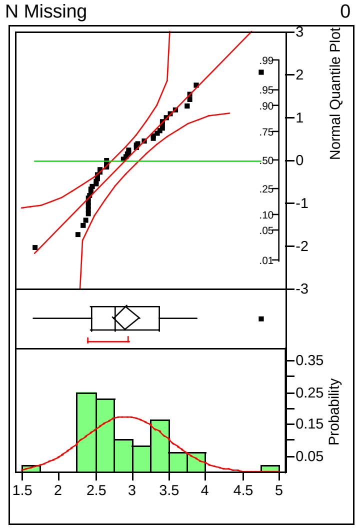
Figure 6.2 continued: (L47).

Mean	0.0208333
Std Dev	0.015441
Std Err Mean	0.0022287
upper 95% Mean	0.0253169
lower 95% Mean	0.0163497
N	48
Sum Wgt	48
Sum	1
Variance	0.0002384
Skewness	3.3658796
Kurtosis	14.859688
CV	74.116974
N Missing	0

Mean	2.9184792
Std Dev	0.5706606
Std Err Mean	0.0823678
upper 95% Mean	3.0841817
lower 95% Mean	2.7527766
N	48
Sum Wgt	48
Sum	140.087
Variance	0.3256535
Skewness	0.7637108
Kurtosis	0.9647156
CV	19.553356
N Missing	0

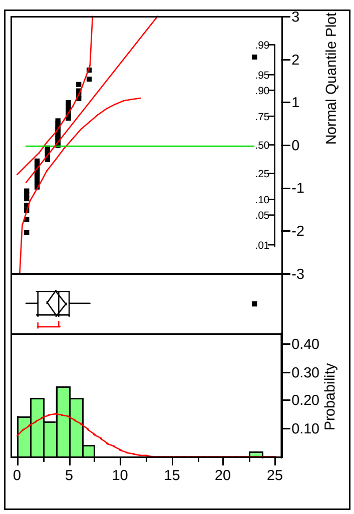
Relative Length

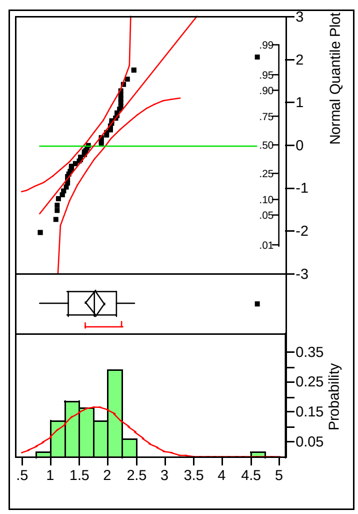




Mean Depth

Connectivity





Integration

Mean	3.8333333
Std Dev	3.2897865
Std Err Mean	0.4748398
upper 95% Mean	4.7885877
lower 95% Mean	2.8780789
N	48
Sum Wgt	48
Sum	184
Variance	10.822695
Skewness	4.3216587
Kurtosis	24.831383
CV	85.820517
N Missing	0

Mean	1.7916875
Std Dev	0.5957422
Std Err Mean	0.085988
upper 95% Mean	1.964673
lower 95% Mean	1.618702
N	48
Sum Wgt	48
Sum	86.001
Variance	0.3549088
Skewness	2.1644158
Kurtosis	9.6467853
CV	33.250341
N Missing	0

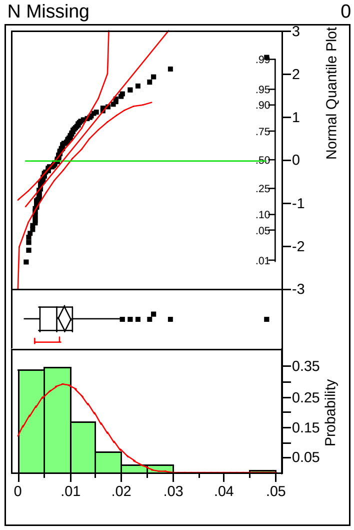
48) L48: vitra

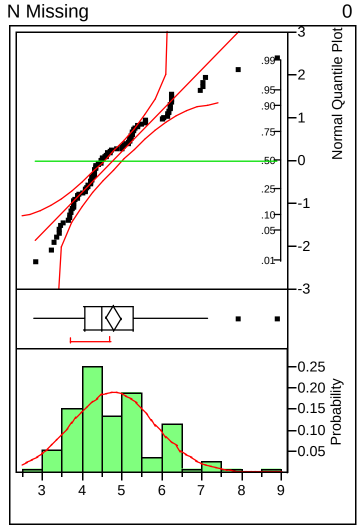
Figure 6.2 continued: (L48).

Mean	0.009009
Std Dev	0.006807
Std Err Mean	0.0006461
upper 95% Mean	0.0102894
lower 95% Mean	0.0077286
N	111
Sum Wgt	111
Sum	1
Variance	0.0000463
Skewness	2.535309
Kurtosis	10.018486
CV	75.557152
N Missing	0

Mean	4.8024234
Std Dev	1.0517554
Std Err Mean	0.0998282
upper 95% Mean	5.0002595
lower 95% Mean	4.6045873
N	111
Sum Wgt	111
Sum	533.069
Variance	1.1061895
Skewness	1.0730325
Kurtosis	1.5921507
CV	21.900514
N Missing	0

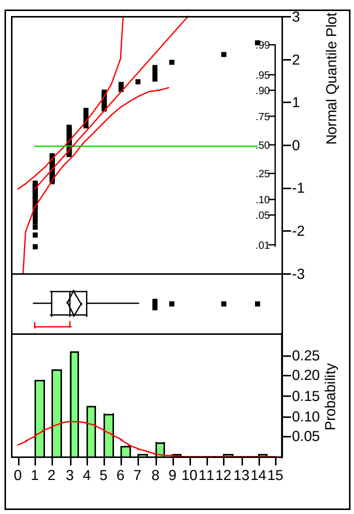
Relative Length

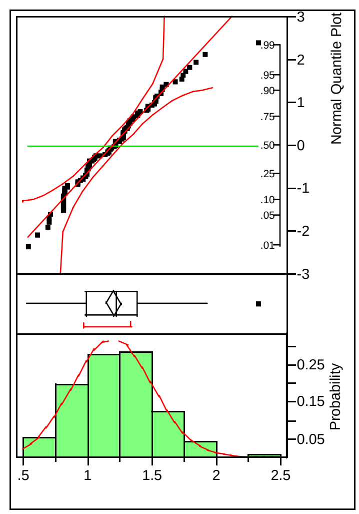




Mean Depth

Connectivity





Integration

Mean	3.2792793
Std Dev	2.220447
Std Err Mean	0.2107555
upper 95% Mean	3.6969472
lower 95% Mean	2.8616113
N	111
Sum Wgt	111
Sum	364
Variance	4.9303849
Skewness	2.014459
Kurtosis	6.0583322
CV	67.711434
N Missing	0

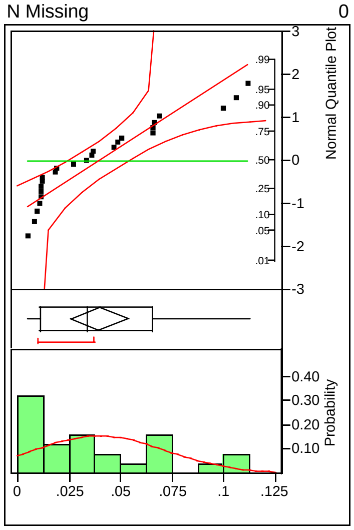
Mean	1.206027
Std Dev	0.3098428
Std Err Mean	0.029409
upper 95% Mean	1.2643087
lower 95% Mean	1.1477453
N	111
Sum Wgt	111
Sum	133.869
Variance	0.0960026
Skewness	0.4877572
Kurtosis	0.6457395
CV	25.6912
N Missing	0

49) L49: weyer

Figure 6.2 continued: (L49).

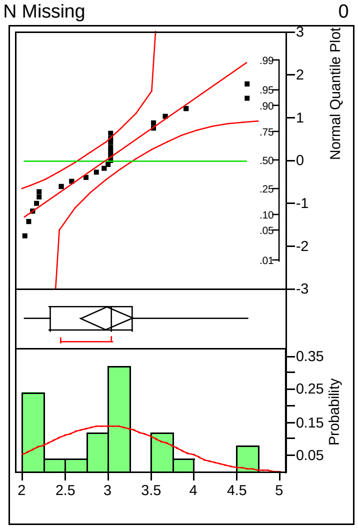
Relative Length

Mean	0.04
Std Dev	0.0324627
Std Err Mean	0.0064925
upper 95% Mean	0.0533999
lower 95% Mean	0.0266001
N	25
Sum Wgt	25
Sum	1
Variance	0.0010538
Skewness	0.9351027
Kurtosis	-0.099518
CV	81.156647
N Missing	0

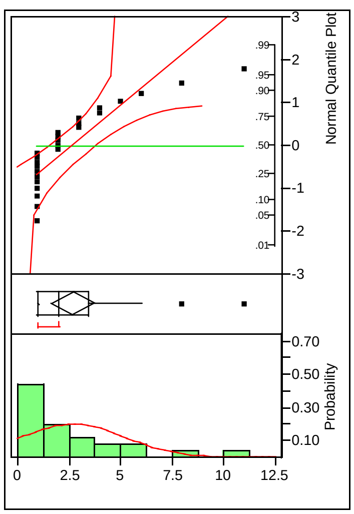


Mean Depth

Mean	2.98676
Std Dev	0.712471
Std Err Mean	0.1424942
upper 95% Mean	3.2808536
lower 95% Mean	2.6926664
N	25
Sum Wgt	25
Sum	74.669
Variance	0.5076149
Skewness	0.7903813
Kurtosis	0.5046018
CV	23.854311
N Missing	0

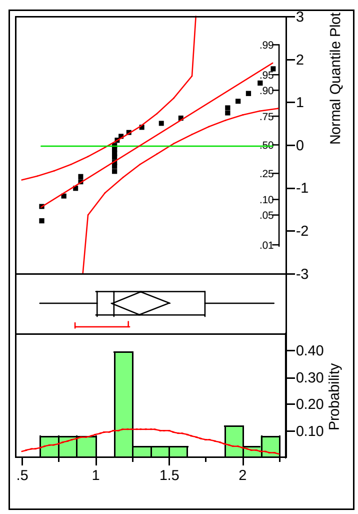


Connectivity



Mean	2.72
Std Dev	2.5086517
Std Err Mean	0.5017303
upper 95% Mean	3.7555205
lower 95% Mean	1.6844795
N	25
Sum Wgt	25
Sum	68
Variance	6.2933333
Skewness	2.0322265
Kurtosis	4.3194642
CV	92.229842
N Missing	0

Integration



Mean	1.30788
Std Dev	0.4675874
Std Err Mean	0.0935175
upper 95% Mean	1.5008906
lower 95% Mean	1.1148694
N	25
Sum Wgt	25
Sum	32.697
Variance	0.2186379
Skewness	0.6249508
Kurtosis	-0.679753
CV	35.751549
N Missing	0

50) L50: wma

Figure 6.2 continued: (L50).

Table 6.2: Syntactic analysis of 50 actual layouts and shape analysis of their floorplates.

layout	type	lines	relleng skewn	mean connec	connec skewn	mean md	md skewn	mean integr	integr skewn	rgd	cf
L1	b	135	3.581	3.277	3.584	4.044	0.687	1.653	0.798	1.335	1.534
L2	b	106	4.390	3.755	4.038	3.680	-0.023	1.655	1.460	1.157	0.706
L3	b	44	2.477	2.409	4.234	3.307	0.501	1.414	1.422	1.173	0.657
L4	u-s	20	1.291	2.400	2.468	2.584	-0.425	1.409	1.713	1.221	0.440
L5	u-s	56	4.471	3.321	1.457	3.725	-0.232	1.291	1.567	1.424	0.525
L6	u-s	73	2.607	3.315	2.677	3.107	0.026	1.852	1.873	1.292	1.276
L7	u-s	66	3.113	3.636	1.893	3.198	0.531	1.695	0.516	1.289	0.975
L8	u-s	31	1.389	3.677	1.117	2.750	0.506	1.631	0.751	1.189	0.968
L9	u-d	131	1.914	5.221	1.869	4.022	1.176	1.609	0.427	1.060	0.458
L10	u-s	55	1.779	3.564	2.413	3.392	1.111	1.490	0.672	1.104	0.207
L11	u-s	50	2.478	3.280	2.231	3.652	0.542	1.298	0.769	1.613	1.529
L12	u-s	70	1.720	3.257	1.952	4.103	0.315	1.238	0.792	1.132	0.802
L13	u-s	37	1.295	3.784	1.393	2.557	-0.550	1.928	1.459	1.280	1.007
L14	b	77	3.068	2.805	4.197	3.748	0.234	1.479	1.371	1.327	1.345
L15	u-s	69	0.590	3.449	1.275	4.233	0.316	1.157	0.519	1.246	1.176
L16	u-s	39	2.106	2.667	1.923	3.057	-0.264	1.488	1.537	1.177	0.755
L17	u-s	47	2.147	3.191	2.504	3.067	0.109	1.623	1.550	1.087	1.130
L18	u-s	54	1.789	3.259	1.959	3.552	0.638	1.383	0.922	1.343	1.087
L19	u-d	59	0.659	4.407	1.250	3.486	0.512	1.482	0.667	1.010	0.189
L20	b	35	2.430	2.800	3.123	2.980	0.302	1.506	0.981	1.259	0.783
L21	u-s	29	1.856	2.690	1.479	3.237	0.296	1.213	1.513	1.675	0.944
L22	u-d	100	2.194	4.140	1.355	4.084	0.304	1.403	0.955	1.061	0.413
L23	u-s	55	2.232	3.273	1.556	3.519	0.460	1.393	1.327	1.273	0.912
L24	u-s	92	2.526	2.870	2.641	3.590	-0.140	1.610	1.640	1.338	0.932
L25	u-s	46	1.553	3.478	2.347	3.208	-0.279	1.489	1.760	1.125	1.057
L26	u-s	120	1.846	3.833	2.578	4.044	0.776	1.538	0.869	1.019	0.436
L27	b	78	2.976	3.308	3.264	3.646	0.898	1.510	0.792	1.365	1.477
L28	u-s	35	1.493	2.571	1.462	3.590	0.896	1.141	1.005	1.216	0.984
L29	u-d	26	1.769	4.692	1.980	2.215	1.389	2.179	1.389	1.167	0.000
L30	u-d	97	1.424	4.804	1.456	3.909	0.784	1.514	0.703	1.075	0.607
L31	u-d	135	1.535	4.400	1.740	4.907	0.196	1.216	0.642	1.167	0.399
L32	b	55	2.344	3.309	2.846	3.599	0.667	1.373	0.371	1.270	1.030
L33	b	73	4.325	3.315	3.241	3.576	0.339	1.523	1.273	1.202	0.804
L34	u-d	37	2.100	4.324	1.925	2.719	0.264	1.770	1.261	1.280	0.748
L35	u-s	28	0.992	3.714	1.604	2.503	-0.028	1.754	1.143	1.122	0.856
L36	u-d	81	0.928	4.667	1.108	4.059	0.855	1.366	0.268	1.159	0.505
L37	u-s	43	1.824	3.209	2.060	3.349	0.325	1.356	1.260	1.104	0.586
L38	u-s	39	0.868	3.333	0.757	3.413	0.680	1.284	0.693	1.160	0.849
L39	u-s	18	1.398	2.556	1.435	2.778	0.336	1.210	0.858	1.031	0.000
L40	u-s	26	1.512	3.615	2.530	2.489	0.933	1.764	1.009	1.031	0.000
L41	u-d	34	1.374	6.059	2.318	2.018	0.513	2.907	2.598	1.031	0.000
L42	u-d	62	1.497	4.194	1.492	3.428	0.491	1.510	0.611	1.117	0.634
L43	u-d	126	2.179	5.476	2.123	3.178	0.554	2.119	1.788	1.178	0.917
L44	u-s	30	2.033	3.067	1.227	3.322	0.058	1.174	1.309	1.351	1.450
L45	u-d	71	1.122	5.972	1.423	2.796	1.230	2.175	0.623	1.046	0.406
L46	b	108	2.886	3.648	3.244	3.475	0.125	1.792	1.974	1.231	1.249
L47	u-d	89	1.634	4.697	1.762	3.622	0.307	1.578	0.949	1.094	0.681
L48	b	48	3.366	3.833	4.322	2.918	0.764	1.792	2.164	1.367	0.356
L49	u-s	111	2.535	3.279	2.014	4.802	1.073	1.206	0.488	1.136	0.584
L50	u-s	25	0.935	2.720	2.032	2.987	0.790	1.308	0.625	1.046	0.129
mean		63.42	2.051	3.650	2.178	3.384	0.437	1.549	1.112	1.203	0.750

Table 6.3: Pairwise correlations and significance probabilities for the analysis of 50 office layouts.

all 50	rel length skewness	mean connectivity	connectivity skewness	mean mean depth	mean depth skewness	mean integration	integration skewness
lines	0.319 p=0.024	0.371 p=0.008	0.199 p=0.166	0.727 p=0.000	0.165 p=0.251	0.015 p=0.915	-0.205 p=0.154
rel length skewness		-0.220 p=0.126	0.648 p=0.000	0.198 p=0.168	-0.155 p=0.284	0.021 p=0.888	0.304 p=0.032
mean connectivity			-0.247 p=0.084	-0.074 p=0.608	0.367 p=0.009	0.661 p=0.000	-0.029 p=0.841
connectivity skewness				-0.009 p=0.953	-0.031 p=0.832	0.187 p=0.195	0.385 p=0.006
mean mean depth					0.122 p=0.398	-0.604 p=0.000	-0.494 p=0.000
mean depth skewness						0.107 p=0.459	-0.495 p=0.000
mean integration							0.500 p=0.000

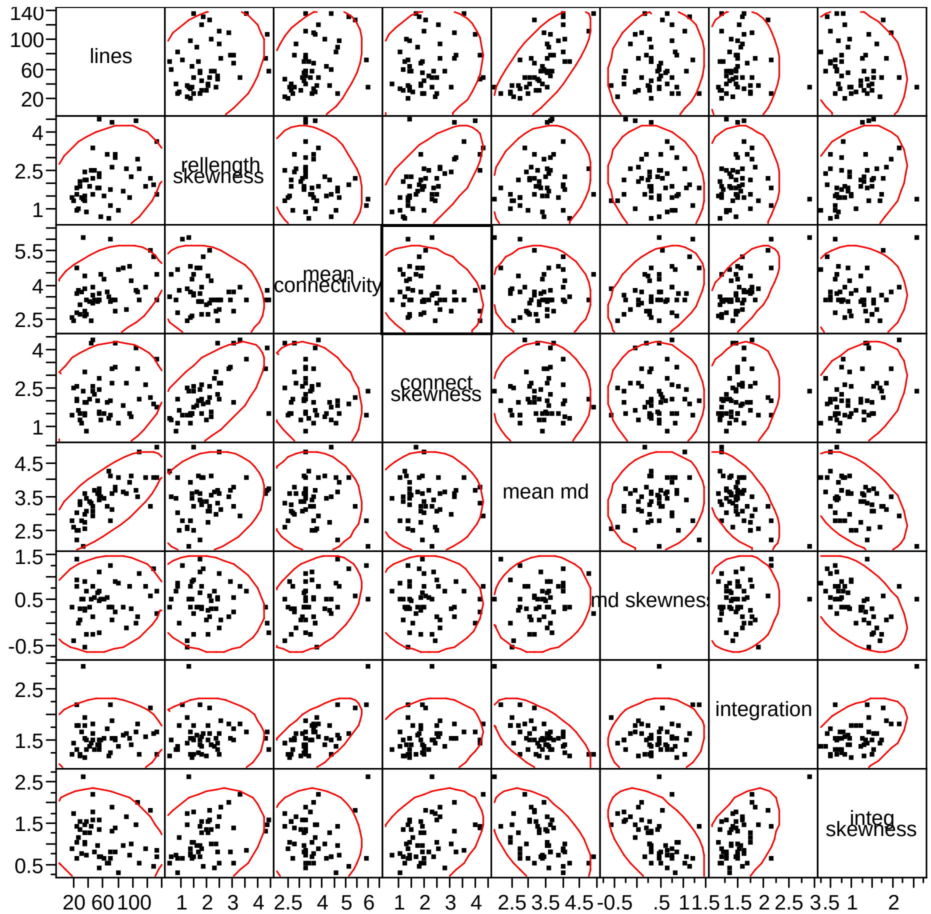


Figure 6.3: Multivariate correlation scatterplot matrix for measures of 50 office layouts, ellipse alpha=0.95.

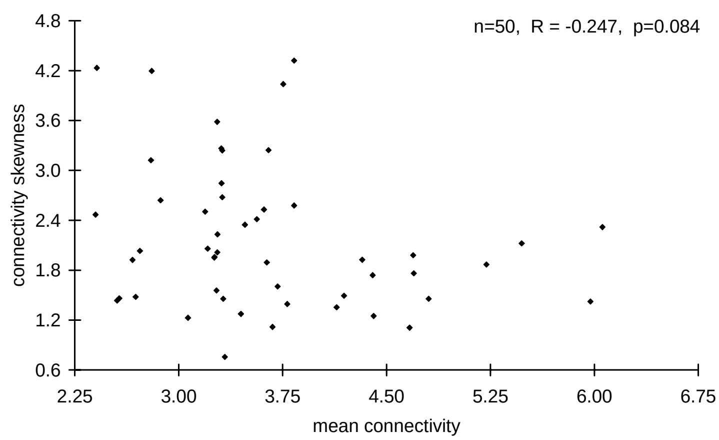


Figure 6.4: Scatterplot of Mean Connectivity against Connectivity Skewness for 50 actual office layouts.

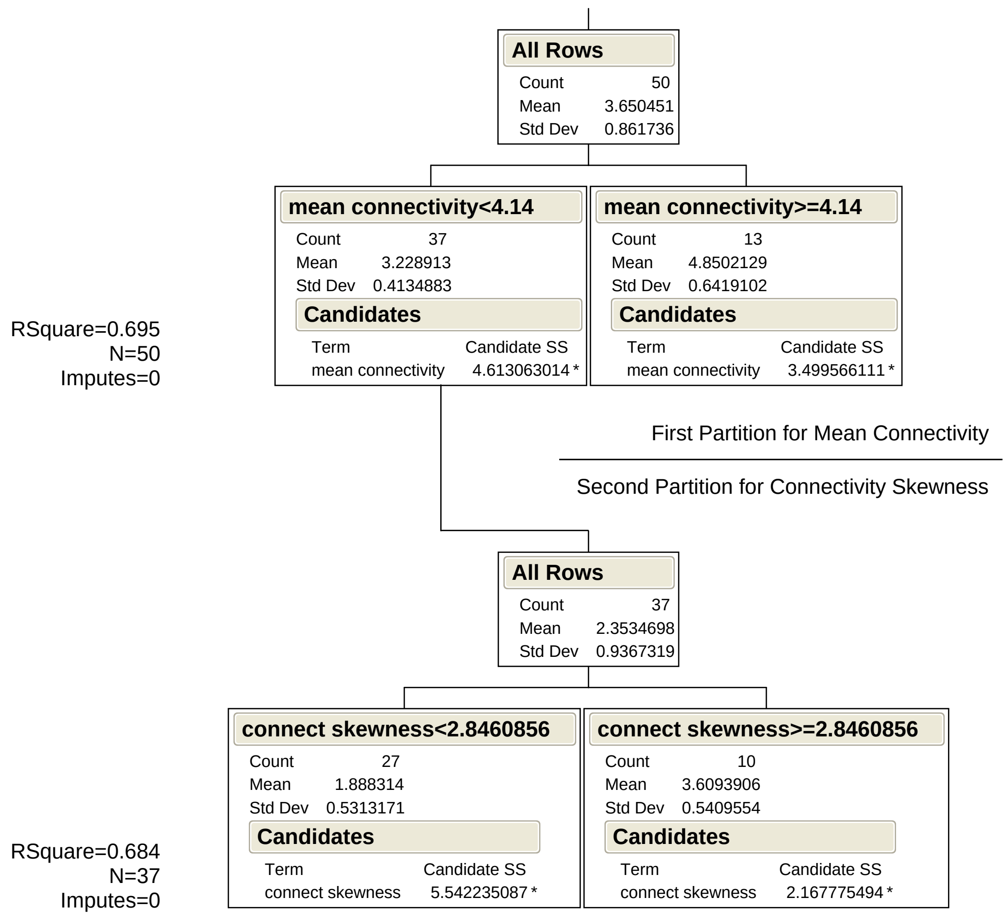


Figure 6.5: Two-step partitioning: First splitting the sample according to Mean Connectivity into two groups of 37 and 13; second splitting the larger group of 37 according to Connectivity Skewness into two parts of 27 and 10.

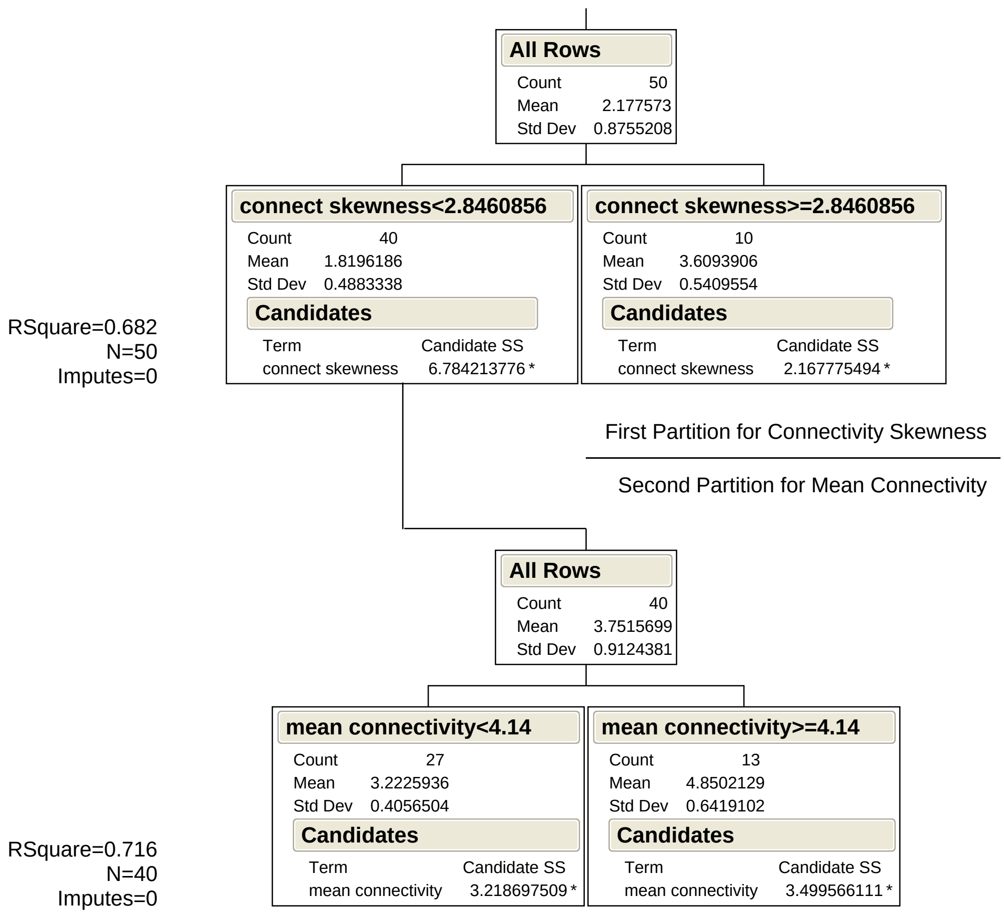


Figure 6.5: Two-step partitioning: First splitting the sample according to Connectivity Skewness into two groups of 40 and 10; second splitting the larger group of 40 according to Mean Connectivity into two parts of 27 and 13.

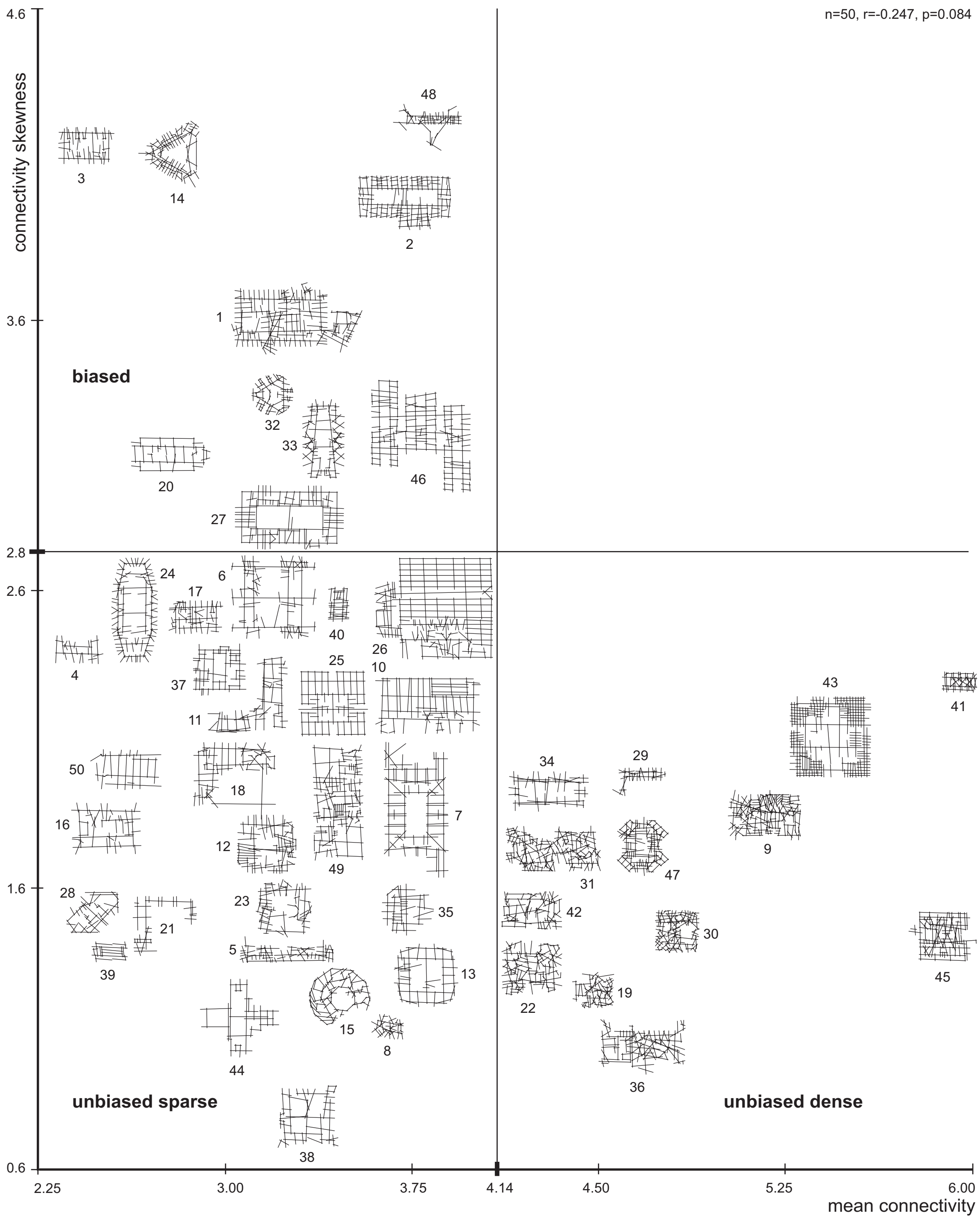


Figure 6.7: Fifty line-representations of actual office layouts compared . Three types of layout are proposed according to density and connectivity bias.

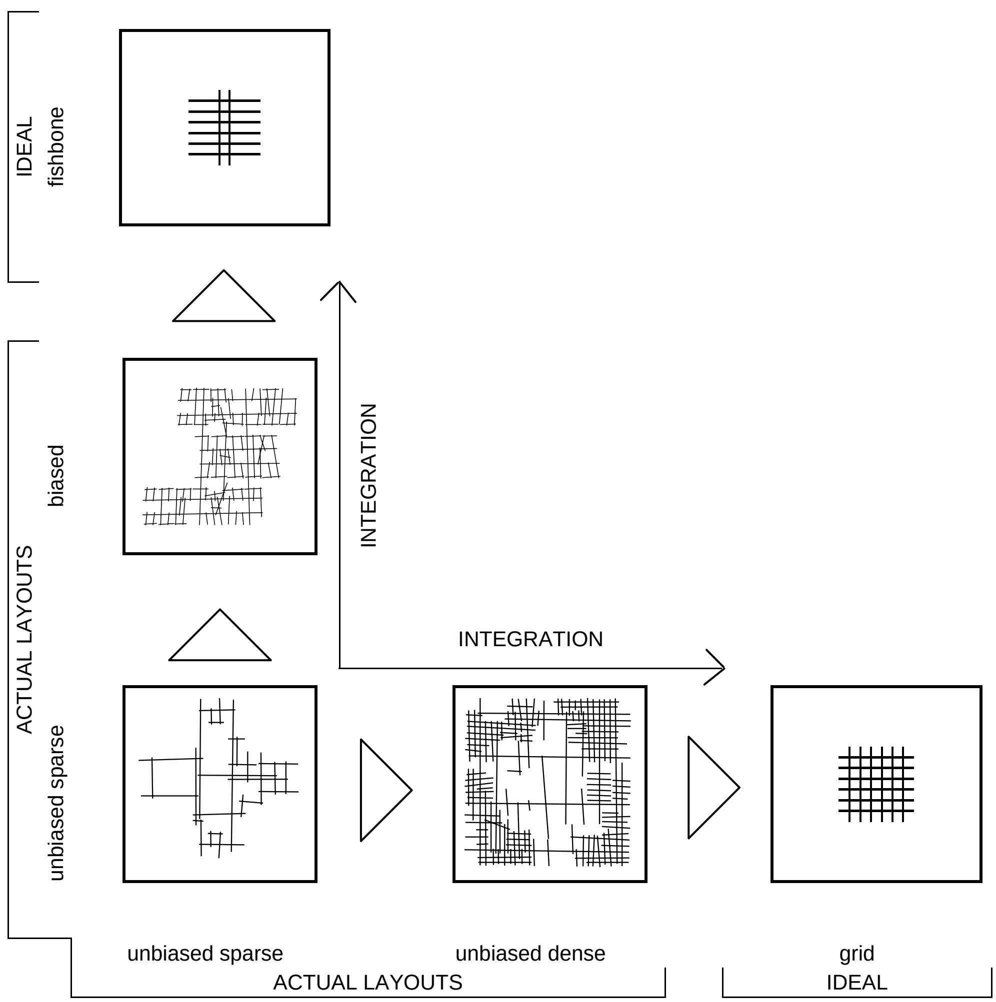


Figure 6.8: Ideal layout types as representatives of alternative principles of increasing layout integration.

biased n=10 **75.900**	all n=50 **63.420**
50.519 n=27 unbiased_sparse	**80.615** n=13 unbiased_dense

number of lines

biased n=10 **3.184**	all n=50 **2.051**
1.866 n=27 unbiased_sparse	**1.564** n=13 unbiased_dense

relative length skewness

biased n=10 **3.246**	all n=50 **3.650**
3.223 n=27 unbiased_sparse	**4.850** n=13 unbiased_dense

mean connectivity

biased n=10 **3.609**	all n=50 **2.178**
1.888 n=27 unbiased_sparse	**1.677** n=13 unbiased_dense

connectivity skewness

biased n=10 **3.497**	all n=50 **3.384**
3.326 n=27 unbiased_sparse	**3.419** n=13 unbiased_dense

mean mean depth

biased n=10 **0.449**	all n=50 **0.437**
0.326 n=27 unbiased_sparse	**0.660** n=13 unbiased_dense

mean depth skewness

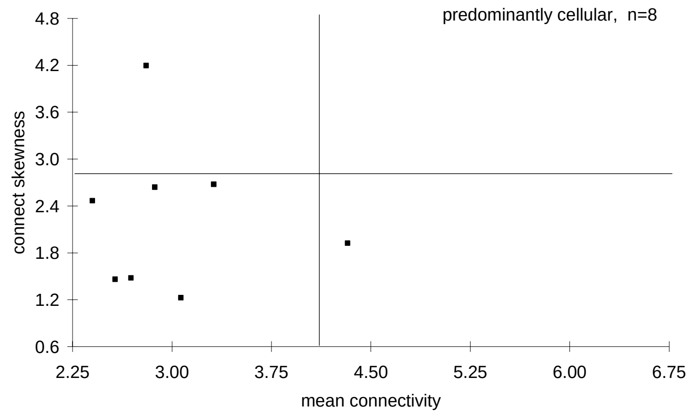
biased n=10 **1.570**	all n=50 **1.549**
1.442 n=27 unbiased_sparse	**1.756** n=13 unbiased_dense

mean integration

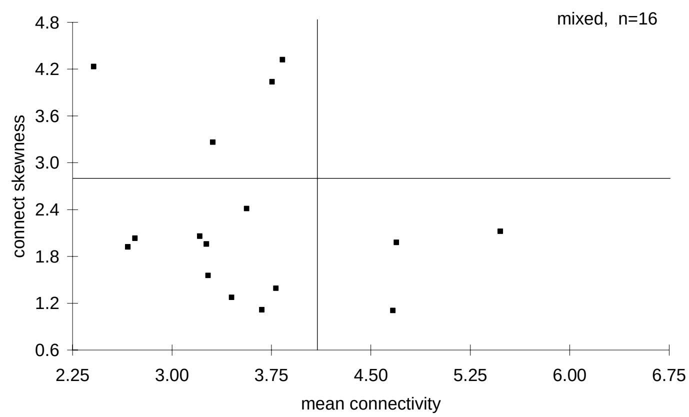
biased n=10 **1.261**	all n=50 **1.112**
1.116 n=27 unbiased_sparse	**0.991** n=13 unbiased_dense

integration skewness

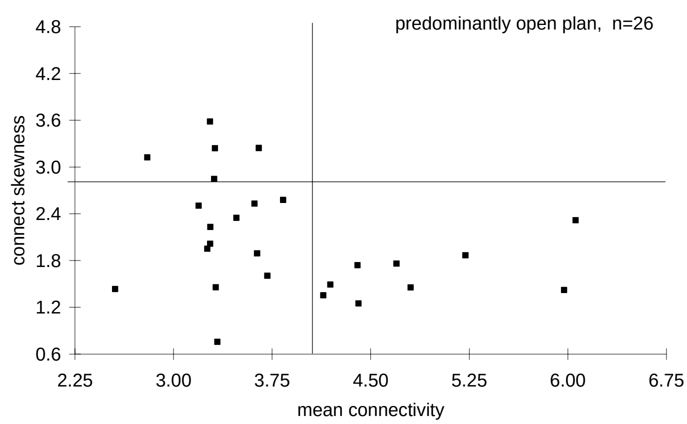
Figure 6.9: Comparison of 8 layout measures among three proposed types and the entire sample.



a)



b)



c)

Figure 6.10: Scatterplots of Mean Connectivity against Connectivity Skewness for actual office layouts split according to: a) “predominantly cellular”, b) “mixed” and c) “predominantly open”.

all
n=50

63.420

49.125	**57.313**	**71.577**
n=8 cellular	n=16 mixed	n=26 open plan

number of lines

all
n=50

2.051

2.122	**2.001**	**2.060**
n=8 cellular	n=16 mixed	n=26 open plan

relative length skewness

all
n=50

3.650

3.005	**3.609**	**3.875**
n=8 cellular	n=16 mixed	n=26 open plan

mean connectivity

all
n=50

2.178

2.260	**2.300**	**2.077**
n=8 cellular	n=16 mixed	n=26 open plan

connectivity skewness

all
n=50

3.384

3.237	**3.275**	**3.497**
n=8 cellular	n=16 mixed	n=26 open plan

mean mean depth

all
n=50

0.437

0.151	**0.517**	**0.477**
n=8 cellular	n=16 mixed	n=26 open plan

mean depth skewness

all
n=50

1.549

1.456	**1.573**	**1.563**
n=8 cellular	n=16 mixed	n=26 open plan

mean integration

all
n=50

1.112

1.461	**1.147**	**0.984**
n=8 cellular	n=16 mixed	n=26 open plan

integration skewness

Figure 6.11: Comparison of 8 layout measures among three heuristic types and the entire sample.

Table 6.4: Ranking orders of 8 layout measures in three types compared between the two classifications.

heuristic types according to % of open & cellular	proposed types according to bias & density of linear maps
number of lines	number of lines
o-p > m > $\boxed{c}$	u-d > b > $\boxed{u\text{-}s}$
relative length skewness	relative length skewness
c > o-p > m	b > u-s > u-d
mean connectivity	mean connectivity
o-p > m > $\boxed{c}$	u-d > b > $\boxed{u\text{-}s}$
connectivity skewness	connectivity skewness
m > $\boxed{c}$ > o-p	b > $\boxed{u\text{-}s}$ > u-d
mean mean depth	mean mean depth
o-p > m > $\boxed{c}$	b > u-d > $\boxed{u\text{-}s}$
mean depth skewness	mean depth skewness
m > o-p > $\boxed{c}$	u-d > b > $\boxed{u\text{-}s}$
mean integration	mean integration
m > o-p > $\boxed{c}$	u-d > b > $\boxed{u\text{-}s}$
integration skewness	integration skewness
m > $\boxed{c}$ > o-p	b > $\boxed{u\text{-}s}$ > u-d

Table 6.5: Pairwise correlations and significance probabilities between shape measures and layout measures for the sample of 50 examples.

		lines	relleng skewn	mean connec	connec skewn	mean md	md skewn	mean integr	integr skewn	rgd	cf
50 all	rgd	-0.110 p=0.448	0.429 p=0.002	-0.394 p=0.005	0.170 p=0.237	0.071 p=0.624	-0.237 p=0.098	-0.228 p=0.111	0.192 p=0.181		0.625 p=0.000
	cf	0.156 p=0.268	0.313 p=0.027	-0.347 p=0.014	0.178 p=0.214	0.248 p=0.083	-0.315 p=0.026	-0.227 p=0.112	0.039 p=0.786	0.625 p=0.000	

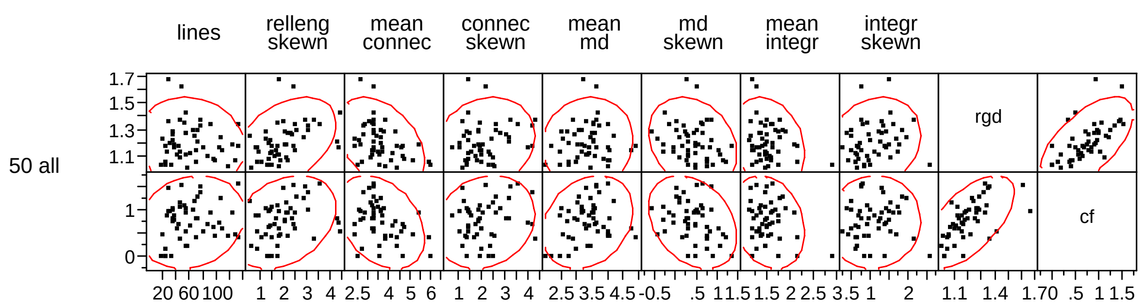


Figure 6.12: Multivariate correlation scatterplot matrix between shape measures and layout measures for the sample of 50 examples, ellipse alpha=0.95.

Table 6.6: Pairwise correlations and significance probabilities between shape measures and layout measures for the sub-sample of 10 biased, 27 unbiased-sparse and 13 unbiased-dense layouts.

		lines	relleng skewn	mean connec	connec skewn	mean md	md skewn	mean integr	integr skewn	rgd	cf
10 b	rgd	0.022 p=0.952	-0.211 p=0.559	0.151 p=0.678	0.010 p=0.978	0.028 p=0.939	0.695 p=0.026	0.164 p=0.651	-0.115 p=0.751		0.398 p=0.255
	cf	0.611 p=0.061	-0.121 p=0.739	-0.100 p=0.784	-0.370 p=0.292	0.757 p=0.011	0.154 p=0.672	-0.110 p=0.762	-0.473 p=0.168	0.398 p=0.255	
27 u-s	rgd	-0.036 p=0.860	0.413 p=0.032	-0.158 p=0.430	-0.194 p=0.334	0.132 p=0.512	-0.240 p=0.227	-0.182 p=0.362	0.244 p=0.220		0.598 p=0.001
	cf	0.113 p=0.576	0.130 p=0.518	0.143 p=0.476	-0.185 p=0.356	0.183 p=0.363	-0.310 p=0.116	0.022 p=0.914	0.219 p=0.272	0.598 p=0.001	
13 u-d	rgd	-0.066 p=0.832	0.462 p=0.112	-0.339 p=0.257	0.258 p=0.395	-0.036 p=0.908	-0.190 p=0.536	-0.130 p=0.673	0.059 p=0.849		0.458 p=0.116
	cf	0.479 p=0.098	0.399 p=0.177	-0.186 p=0.543	-0.076 p=0.806	0.344 p=0.250	-0.352 p=0.239	-0.383 p=0.197	-0.238 p=0.434	0.458 p=0.116	

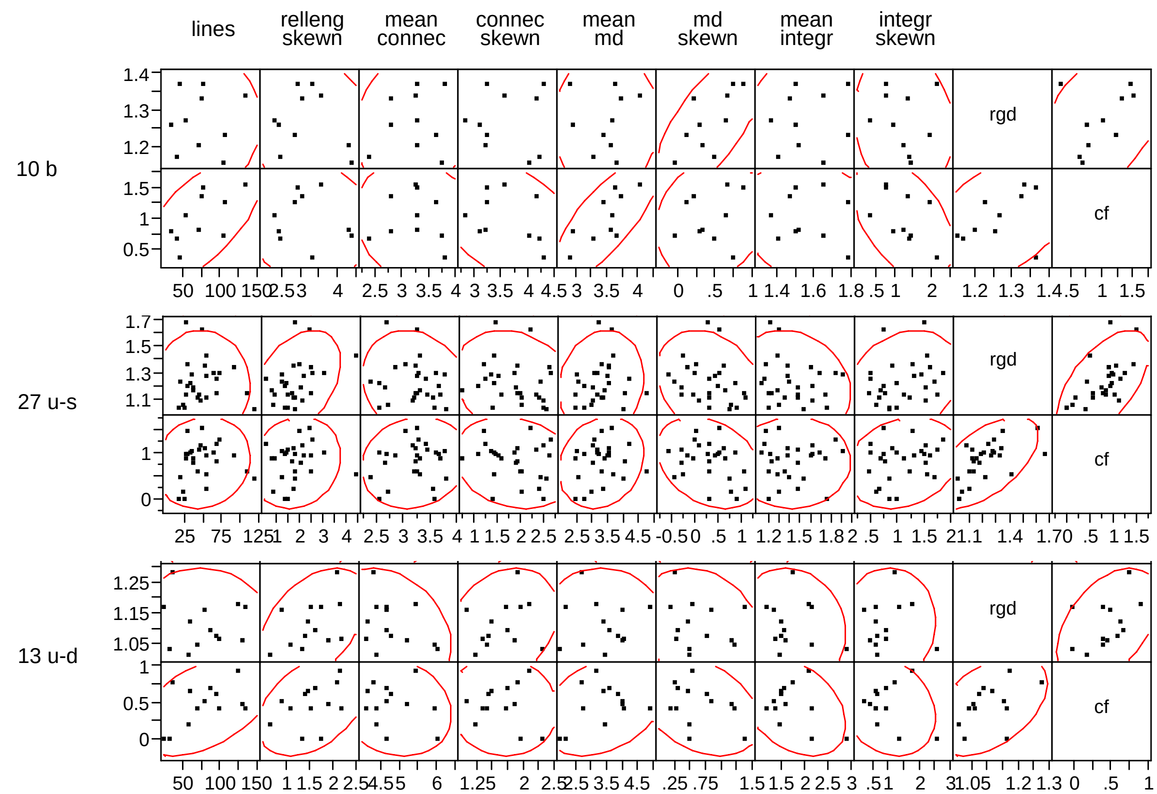


Figure 6.13: Multivariate correlation scatterplot matrix between shape measures and layout measures for the sub-samples of 10 biased, 27 unbiased-sparse and 13 unbiased-dense layouts, ellipse alpha=0.95.

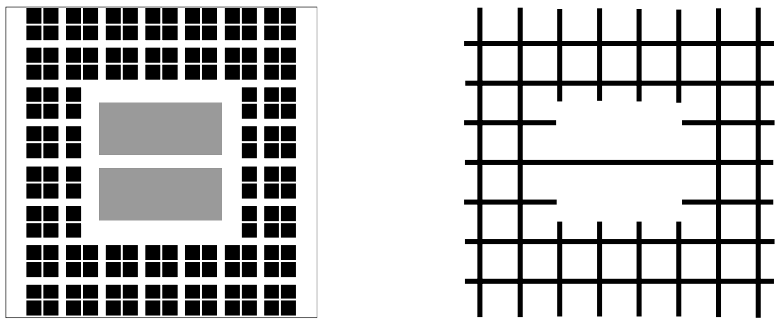


Figure 6.14: The grid hypothetical layout and its linear representation with axial lines drawn over circulation spaces.

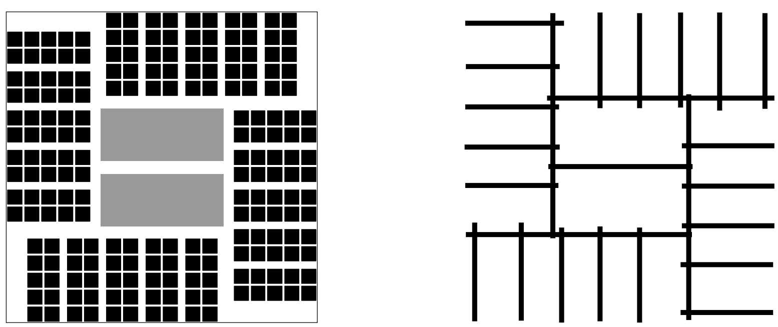


Figure 6.15: The fishbone hypothetical layout and its linear representation with axial lines drawn over circulation spaces.

Chapter Seven

Principles of the Interaction between Ideal Layouts and Simple Shapes

Outline

The first part of the model, discussed in the previous chapter, formulated two theoretical layouts unbiased grids and biased fishbones as representatives of fundamental differences found in actual layouts and primarily representing open plan configurations. This chapter seeks to discover the mathematical principles underlying the relationship between layout Integration and shape metrics. The experimentation with hypothetical layouts and theoretical shapes addresses two fundamental questions: first, whether the effect of shape on layouts is bound by consistent principles; second, whether differences exist on the way shapes effect the two types of unbiased and biased layouts. This inquiry is closely related to the core question raised by this thesis: what is the effect of the floorplate shape on the spatial features of layouts. The two ideal layouts, the unbiased grids and the biased fishbones, have been inserted into a large number of theoretical shapes derived by systematic modifications of a few basic shapes by removing one or two shape units. The analysis reveals that shapes affect different kinds of layouts in different ways primarily through the interaction between shape-regions and through particular layout elements. Significant patterns between characteristics of shape and integration in hypothetical duos have provided the foundation for proposing two hypotheses on the relationship between layout Integration and floorplate shape metrics.

7.1 Theoretical Experiments with Simple Shapes

The two ideal layouts of grids and fishbones are inserted in three simple hypothetical floorplate shapes, square, oblong, and L-shape, each consisting of 36 unit tiles. The grid layout is composed by allocating four square-shaped cubicles of workplaces in each shape unit so that the cubicles abut the unit edges and leave a cross-shaped circulation space in its middle (**figure 7.1**). This layout can also be imagined as being composed of straight circulation corridors that pass through the center of each shape unit creating clusters of four workspaces. As a result, each floorplate accommodates 144 cubicle workspaces. The fishbone layout is composed of two main organizing circulation segments that cross the secondary branches, positioned parallel to each other and perpendicular to the main elements (**figure 7.2**). In order to avoid having a line with infinite Integration (connected to all other lines in the system), double fishbone plans are used instead of the more obvious single fishbone. Back-to-back pairs of cubicles are grouped in longer strings, four or more in a row. In this case, the density of cubicles per circulation line is higher in one direction, and the density of intersections between circulation lines is higher in the other.

The following experimentations with theoretical shapes and ideal layouts will use equal degrees of layout grain for shapes with constant area. Consequentially, the effect of grain is non existent. The experiments with hypothetical layouts and actual floorplates, explained in the next chapter, where floorplates of different sizes are involved, will also use equal degrees of grain. However, in these cases, the effect of grain, despite minute, will be considered as an integral part of the effect of shapes on layouts. The index of grain and its effect on layout Integration is explained in Appendix 7.

The analysis of linear maps shows that the elongation of shapes and their breaking into wings inflicts a greater differentiation among Depth values of circulation segments (**figure 7.3**). The aggregate results of the analysis are shown in **figure 7.4**. The first three rows of the table describe grid layouts inserted in the four basic floorplate shapes. The three shapes are ranked as follows with respect to Integration: oblong > square > L-shape. This rank order differs from the rank order of Mean Depth which is: square > oblong > L-shape. The apparent discrepancy is solved when we notice that the number of lines involved also varies and remember that Integration values are relativized according to the number of lines. From an intuitive point of view, the Integration values make better sense. Indeed, while the most compact rectangular floorplate, the square, minimizes grid distances, it is the oblong that will tend to minimize directional distances, as it will tend towards a single double loaded corridor. For these simple floorplates, populated by unbiased dense grid layouts, less compactness implies greater circulation integration. Fragmentation, however, is associated with less integration.

A different situation arises with directionally biased fishbone layouts. For example, the fishbone can be loaded with a vertical or horizontal orientation of the dominant axes, and thus we have to deal with five cases, not three. The Integration inequality is as follows: oblong horizontal > L-shape vertical > square > L-shape horizontal > oblong vertical. Thus, the same floorplate appears in opposite ends of the inequality depending upon the manner in which the layout is loaded onto the floorplate. A fundamental difference between biased and unbiased dense layouts immediately becomes apparent. Rotation by 90 degrees has no impact upon the syntactic properties of unbiased layouts inserted into these basic shapes. However, it has a major impact on the properties of biased layouts. Fishbones are much more integrated when the major circulation axis runs parallel to the longer dimension of the oblong, the elongated oblong and the L-shape than when it runs parallel to the shorter axis. This fundamental difference further confirms the need to look for different principles of correlation between layout Integration and shape for these two types.

7.2 Theoretical Experiments with Systematically Modified Shapes

This section addresses the question of how layout Integration is affected by floorplate shapes which differ not only in their basic proportion, or underlying type, but rather in more detailed elaboration. The more stable unbiased dense layouts are accordingly taken as the starting point for exploring the impact of systematic transformations of the shape upon Integration. Transformations are produced by removing tile units, as shown in **figure 7.5**. The analysis draws inspiration from the theory of partitioning proposed by Hillier (1996). There is, however, an important conceptual shift with respect to Hillier's work on partitions. Hillier held an underlying shape constant and treated it as a field for generating alternative interior plans by applying different partitioning principles **-** even though some of the operations he studied modified the shape (insertion of holes). Here, shape and layout are treated as independent entities, described by independent metrics. The aim is not to develop a theory of how layouts are structured through particular operations and design moves but rather a theory of how a certain kind of layout, the grid, is affected when inserted in different shapes.

Hillier's principle of *centrality* applied to the theory of partitioning states that a more centrally placed partition leads to greater depth gain. A similar finding could be expected regarding the depth gains due to removing unit cells from the shape thus causing interruptions in the circulation map. This, however, is not quite the case. The effect of removing cells does not depend upon the coordinate position of the cell with respect to the floorplate, but rather upon the position of the cell with respect to underlying shape-regions (**figure 7.6**). The presence of these regions and the determination of their boundaries is a major finding resulting from this analysis. For rectangular shapes, square or elongated, there are 3 underlying regions. First, the four corner cells, which is termed region C; second the edge cells, not including corners, which is termed region E; third the cells in the entire middle zone contained by C and E, which is termed region M. The depth gain in layout circulation produced by removing an underlying shape cell is constant from whichever part of the same region the cell is removed.

The effects of regions are demonstrated by considering **figure 7.7**. This exhausts the non-equivalent ways in which a cell can be removed from a square of 36 cells. The resulting 6 shapes are all different according to the metrics of compactness and fragmentation. However, the removal of a cell from a more or less central position in region E produces exactly the same effect upon circulation Mean Depth. The same is true regarding the removal of cells from different positions in region M. Only the Integration values, which are more sensitive to the number of lines involved, follow the centrality principle. Thus, the presence of regions leads to a modification or refinement of the centrality principle.

The analysis of the 10 non-equivalent ways of removing a cell from the oblong produces similar results and the same structure of regions (**figure 7.8**). The analysis of the 36 non-equivalent ways of removing a cell from the L-shape results in a much more complex underlying structure of regions (**figure 7.9**). These different structures of shape regionalization are shown in **figure 7.6**. The principle of regionalization for rectilinear closed shapes with or without holes loaded with unbiased layouts is as follows: First, offset all edges inwards by one tile unit and extend the offset lines until they meet the edges; second, extend the sides of concave angles until they meet the first offset lines. The non-overlapping convex areas produced in this manner are the regions in question. The analysis of grid layouts inserted into the shape (d) (**figure 7.6**) demonstrates the validity of this proposition. The significance of establishing a rule of regionalization lies in demonstrating that the regionalization of floorplate shape with respect to unbiased layouts is entirely driven by the properties of the shape: the shape alone decides what the effects of its own modification through indentations and holes are likely to be.

Hillier’s (1996) principle of contiguity states that inserting two contiguous boundaries leads to greater depth gain than inserting two non-contiguous ones. In order to test for the equivalent of this principle regarding the effects of floorplate shape upon layout Integration the effects of removing two tiles from a floorplate in different combinations are studied (**figure 7.10**). Removing contiguous tiles produced less depth gain than removing non-continuous one, a clear reversal of the principle of contiguity. However, depth gain increases when the tiles removed share only one vertex (**figure 7.11**). Thus, the modified principle of contiguity suggests that depth gain is greater when non-contiguous tiles are removed, unless the tiles removed form a vertex to vertex join.

7.3 The Theoretical Relation between Floorplate Shape Metrics and Layout Integration

Statistical analysis was used to probe further into the differentiated effects of simple shapes upon fishbone and grid layouts. For grid layouts the 73 floorplate-layout pairs obtained after tile elimination are analyzed. There is a strong and significant negative correlation ($r=-0.875$, $p=0.000$) between Integration and Convex Fragmentation (**figure 7.12b**). Relative Grid Distance has a less clear effect on the Integration ($R=0.180$, $p=0.124$). In addition, a careful look at the plot of Integration against Relative Grid Distance ($r=-0.439$, $p=0.000$) reveals bands of points forming parallel negative slopes (**figure 7.12a**). These bands correspond to the different simple underlying shapes (a), (b) and (c) included in the analysis. When each band is analyzed separately, the correlations between Integration and rgd are strong and significant: square (a): ($r=-0.872$, $p=0.000$), oblong (b): ($r=-0.803$, $p=0.000$), and L-shape (c): ($r=-0.691$, $p=0.00$). However, the pattern is not consistent across the whole sample of underlying shapes. In anticipation of later discussion, a distinction has therefore been drawn between the actual floorplate shape, taking into account indentations and holes, and the hull, i.e. the underlying basic shape, from which the floorplate shape under consideration is constructed. Despite the weak overall correlation, there is a tendency for Integration to fall with increasing Relative Grid Distance.

The next experiments are aimed at gauging the effect of shape on biased fishbone layouts. The earlier analysis of fishbone layouts introduced on basic shapes showed that very different shape hulls of the square (a) and L-shape (c-horizontal) produced identical layout conditions (**figure 7.4**). In addition, various indentations occurring on two sides of the underlying shape produce no changes in the structure of the fishbone layout, (**figure 7.13**). As long as shape units underlying the primary lines of the fishbone layout are not affected, no changes are inflicted on the layout. The analysis of fishbones on all non-identical shapes derived by removing one unit from the basic shapes (**figure 7.14, 7.15, 7.16, 7.17** and **7.18**), show the existence of three shape-regions, side S, edge E and middle M, where removing shape units from any position inside them inflicts constant changes on the layout (**figure 7.19**). A fundamental distinction between grids and fishbones becomes apparent. While the regionalization of shapes for unbiased layouts is a product of properties of the shape, for biased layouts such a regionalization is entirely determined by the location of the layout primary lines on the shape. For a vertically oriented fishbone, any horizontal sliding of the spine would transfer the shape-regions along with it.

For biased layouts the 106 different pairs obtained after tile elimination and orientation rotations are analyzed. As predicted, the overall pattern of association between shape properties and Integration is almost random (**figures 7.20a** and **7.20b**). The fact that biased layouts have Integration properties that cannot as well be predicted by floorplate shape is underscored by the poor and insignificant correlations obtained (Integration vs. rgd: r=0.009, p=0.927; Integration vs. cf: r=0.214, p=0.028). Despite weak correlations, the scatterplots for fishbone layouts show distinct horizontal bands of points. The bands which are composed of points with equal Integration values belong to cases where one unit cell was removed from shape-regions S. The other bands of points, where with slight variations of Integration values between points, belong to cases of shape-regions M.

The Integration of a fishbone layout depends on the number of secondary lines intersecting the main spines. This is in turn affected by the length of the spines themselves, given that the rate of intersection is constant under the layout principles used here. When Integration values are plotted against the length of spine for the entire sample of 106 theoretical fishbone cases, a clear correlation appears (**figure 7.20.c**). We also notice three sloping bands of points, each with a perfect correlation (r=1.000, p=0.000), coincide with shapes derived by removing units from shape-regions S, E and M. The stacking of the band of M region below the two other regions S and E, confirms how shape modifications inside region M greatly reduce the layout Integration in comparison to changes elsewhere in the shape. The differential effect of removal of tiles from the different regions would not have been so evident if spines are offset in all possible ways; instead, in the experiments involved here, spines are kept in the same central location as tiles are removed.

The effect of shapes on biased layouts passes via the metric length underlying primary circulation segments. This has implications that must be more fully acknowledged here. In the hypothetical examples discussed in this section, fishbones with only one primary spine direction are used, even when the floorplate shape was fragmented, as with the L-shape. An alternative principle, which would make greater intuitive sense, would lead to more complex fishbone layouts produced by having a prime direction coincide with the longest axis of each major floorplate sub-shape, or wing. In the shapes of office floorplates found in practice, there exist comparatively equal widths among floorplate wings. Under these conditions, and provided that the various floorplate wings have comparable widths, the aggregate length of fishbone spines will be a function of rgd.

7.4 Hypotheses on the Effect of Floorplate Shape on Layout Integration

Experiments of overlaying two kinds of ideal layouts over a sample of theoretical shapes, derived by controlled deformations of basic shapes, showed that the configurational conditions of layouts result from combined conditions of floorplate shapes and principles of layout arrangement.

As is the case for unbiased layouts, when layout composition principles bear characteristics of modularity, uniformity, equality of spreading and repetition, the effect of shapes on layouts is more evident and allows the prediction of their configurational outcome. The effect of shapes on unbiased layouts comes through distinct underlying regions of shapes, which directly reflect the perimeter geometry. These regions are based on offsets of perimeter inwards into the shape with the depth of one shape unit. Only when modifications of shape cross the boundaries between these regions, do we observe changes in the layout structure, likewise, no changes in layouts occur for modifications inside shape regions. A clear ambiguity therefore exists: unbiased layouts are able to overcome certain constraints of shapes through being insensitive to modifications inside regions, while by and large reflecting thoroughly the conditions of shapes. However, the shape index of Convex Fragmentation is a strong and significant predictor of the Integration in unbiased layouts.

As is the case for biased layouts, when layouts are differentiated due to a few primary circulation segments being more connected than others, the effect of shapes onto layouts passes through specific parts of shapes underlying the primary elements of layouts. Similar to uniform layouts, the effect of shape is exerted via distinct regions. However, in contrast to uniform layouts, the arrangement of these regions does not reflect the perimeter of shapes, but the geometry of the layouts. At the degree that deformations of the shapes do not interfere with the main organizing elements, layouts are free from being influenced by most characteristics of container shapes measured by the grid distance and directional distance. For biased layouts, the effect of shapes on layouts primarily concerns the metric dimensions of shape underlying main elements, since such dimensions determine the number of secondary branches that join main organizing elements of layouts. While it is demonstrated that the metric dimension of shapes underlying the primary circulation is a strong and significant predictor of integration in biased layouts, it is speculated that the compactness of a shape as measured by the index of Relative Grid Distance could be a strong predictor of Integration in biased layouts.

Based on the above conclusions, the following two hypotheses can be derived from the analysis of hypothetical layouts set in hypothetical floorplate shapes. First, as layouts become more directionally biased, the Integration is more predictable according to the Relative Grid Distance of floorplate shapes: less compactness is associated with greater Integration (**figure 7.21**). Second, as layouts become more directionally unbiased and more dense, their Integration is more predicable according to the Convex Fragmentation of floorplate shapes: lesser Convex Fragmentation is associated with greater Integration. These hypotheses are tested in the following chapter by inserting grids and fishbones in the floorplates of US buildings included in the sample.

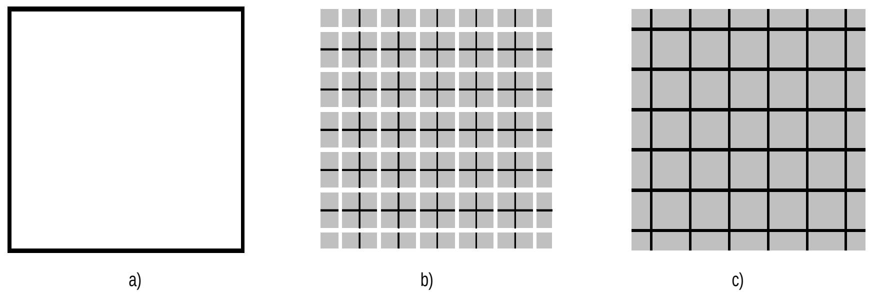


Figure 7.1: a) The square-shaped floorplate; b) the grid hypothetical layout, c) the representation of the layout circulation with linear map.

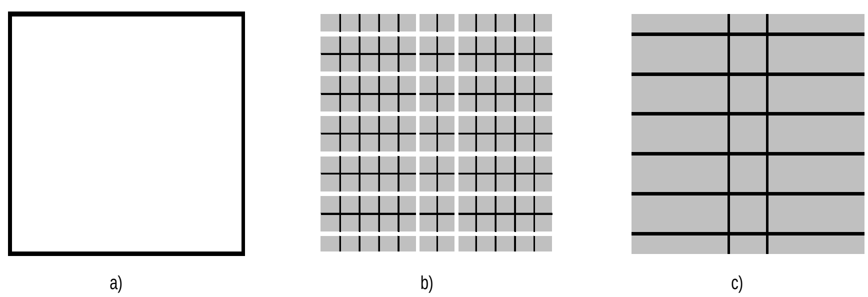


Figure 7.2: a) The square-shaped floorplate; b) the fishbone hypothetical layout, c) the representation of the layout circulation with linear map.

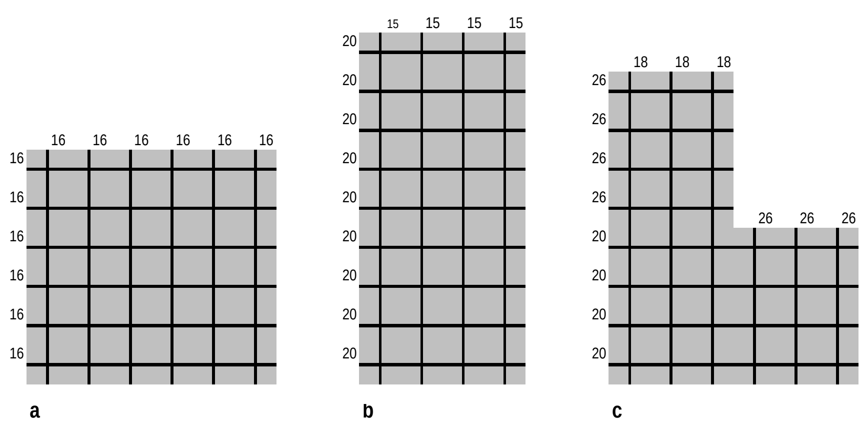


Figure 7.3: Depth values for grid layouts inserted into three basic shapes. Elongated shapes and shapes broken into wings increase the differentiation among circulation Depth values.

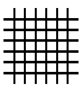
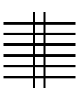
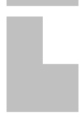
	36 cells 144 cubicles		shape analysis rgd	 cf	layout analysis number of lines	 mean MD	 mean integration
	a		1	0	12	1.455	3.134
	b		1.083	0	13	1.536	3.439
	c		1.106	0.222	14	1.736	2.542
	a		1	0	8	1.571	2.758
	b h		1.083	0	11	1.673	3.770
	b v		1.083	0	6	1.467	1.939
	c v		1.106	0.222	10	1.644	3.457
	c h		1.106	0.222	8	1.571	2.758

Figure 7.4: The effect of simple shapes upon grid and fishbone layouts.

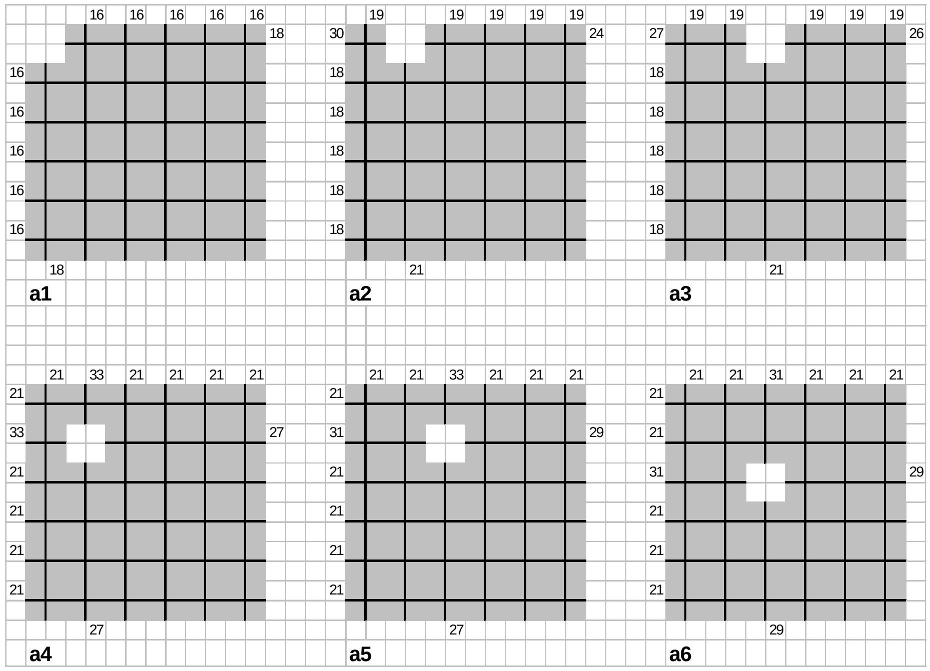


Figure 7.5: Depth values for grid layouts inserted on floorplates derived by removing one unit from a 6x6 square.

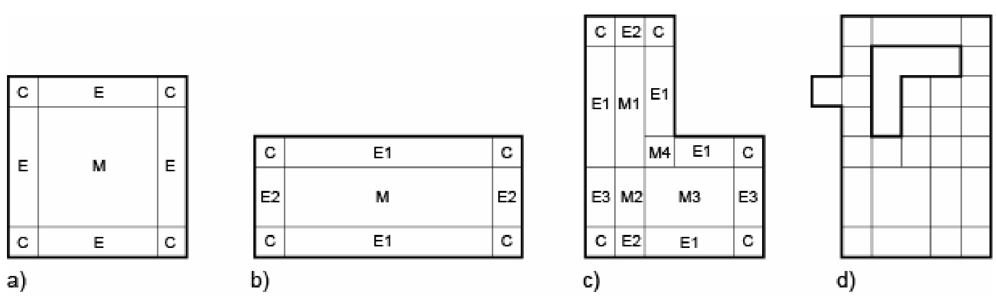


Figure 7.6: Shape regions defined according to the effect of tile removal upon the Integration of grid layouts applied to simple shapes.

region	35 cells 140 cubicles (a)	shape analysis rgd	shape analysis cf	layout analysis number of lines	layout analysis mean MD	layout analysis mean integration
crn C	1	0.997	0.041	12	1.485	2.985
edge E	2	1.011	0.119	13	1.667	2.515
	3	1.017	0.158	13	1.667	2.508
middle M	4	1.024	0.250	14	1.813	2.219
	5	1.031	0.315	14	1.813	2.214
	6	1.038	0.417	14	1.813	2.209

Figure 7.7: Non-equivalent ways of removing one cell from a 6x6 square floorplate and analysis of inserted grid layouts.

region	35 cells 140 cubicles (b)	shape analysis rgd	shape analysis cf	layout analysis number of lines	layout analysis mean MD	layout analysis mean integration
C	1	1.079	0.039	13	1.564	3.217
E1	2	1.088	0.098	14	1.692	2.612
edge E2	3	1.097	0.131	14	1.747	2.644
	4	1.109	0.196	14	1.747	2.626
	5	1.117	0.235	14	1.747	2.617
	6	1.120	0.248	14	1.747	2.614
middle M	7	1.106	0.235	15	1.848	2.297
	8	1.119	0.333	15	1.848	2.284
	9	1.126	0.392	15	1.848	2.277
	10	1.129	0.411	15	1.848	2.275

Figure 7.8: Non-equivalent ways of removing one cell from a 9x4 oblong floorplate and analysis of inserted grid layouts.

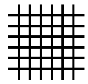
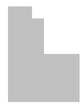
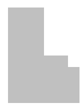
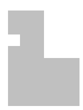
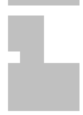
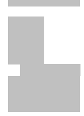
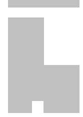
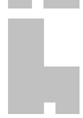
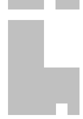
region	35 cells 140 cubicles (c)		shape analysis		layout analysis		
			rgd	cf	number of lines	mean MD	mean integration
corner C	1		1.092	0.238	14	1.758	2.442
	2		1.103	0.238	14	1.758	2.442
	3		1.113	0.240	14	1.758	2.479
	4		1.098	0.240	14	1.758	2.479
	5		1.113	0.273	14	1.758	2.410
edge E1 (to be continued)	6		1.110	0.317	15	1.943	2.108
	7		1.124	0.376	15	1.943	2.093
	8		1.133	0.415	15	1.943	2.084
	9		1.138	0.390	15	1.943	2.060
	10		1.128	0.351	15	1.943	2.070
	11		1.123	0.358	15	1.943	2.113
	12		1.113	0.312	15	1.943	2.123

Figure 7.9: Non-equivalent ways of removing one cell from the 36 unit L-shape floorplate and analysis of inserted grid layouts.

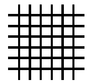
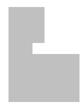
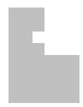
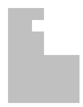
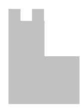
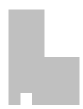
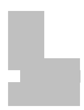
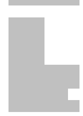
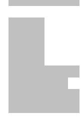
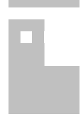
region	35 cells 140 cubicles (c)		shape analysis rgd	cf	layout analysis number of lines	mean MD	mean integration
edge E1 (continued)	13		1.138	0.312	15	1.943	2.123
	14		1.159	0.358	15	1.943	2.113
	15		1.174	0.415	15	1.943	2.084
	16		1.155	0.376	15	1.943	2.093
	17		1.131	0.317	15	1.943	2.108
edge E2	18		1.102	0.264	15	1.867	2.214
	19		1.125	0.338	15	1.867	2.164
edge E3	20		1.137	0.390	15	1.886	2.134
	21		1.128	0.351	15	1.886	2.145
	22		1.109	0.279	15	1.886	2.243
	23		1.115	0.279	15	1.886	2.243
M1	24		1.120	0.362	16	2.025	1.977

Figure 7.9 continued.

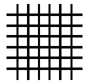
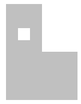
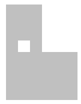
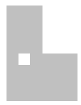
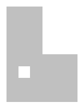
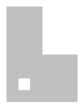
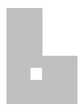
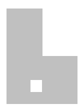
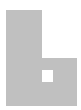
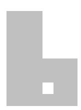
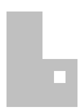
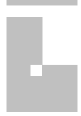
region	35 cells 140 cubicles (c)		shape analysis rgd	cf	layout analysis number of lines	mean MD	mean integration
middle M1	25		1.133	0.434	16	2.025	1.966
	26		1.143	0.480	16	2.025	1.959
	27		1.150	0.495	16	2.025	1.922
middle M2	28		1.149	0.508	16	1.975	1.983
	29		1.140	0.456	16	1.975	1.991
middle M3	30		1.152	0.508	16	2.042	1.905
	31		1.144	0.469	16	2.042	1.913
	32		1.140	0.436	16	2.042	1.978
	33		1.135	0.436	16	2.042	1.978
	34		1.130	0.377	16	2.042	1.986
	35		1.125	0.377	16	2.042	1.986
M4	36		1.225	0.606	16	2.108	1.834

Figure 7.9 continued.

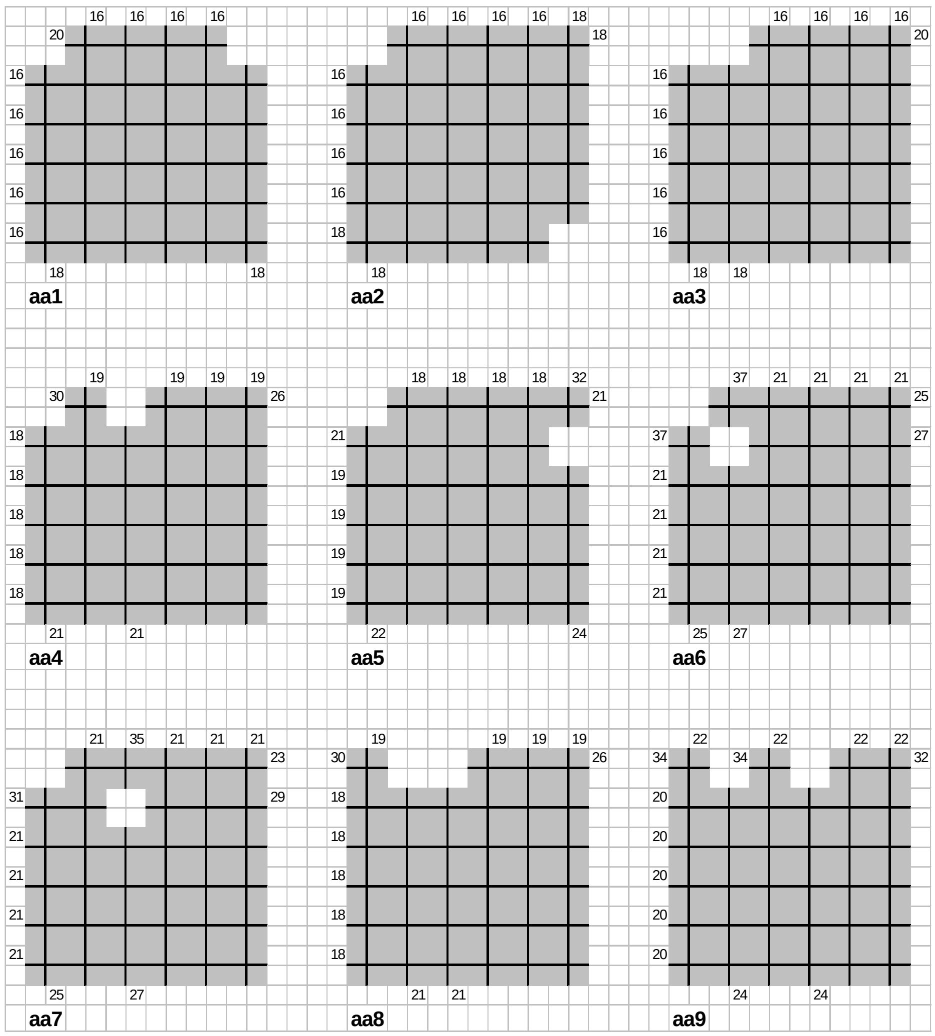


Figure 7.10: Depths values for grid layouts inserted on floorplates derived by removing two cells from a 6x6 square.

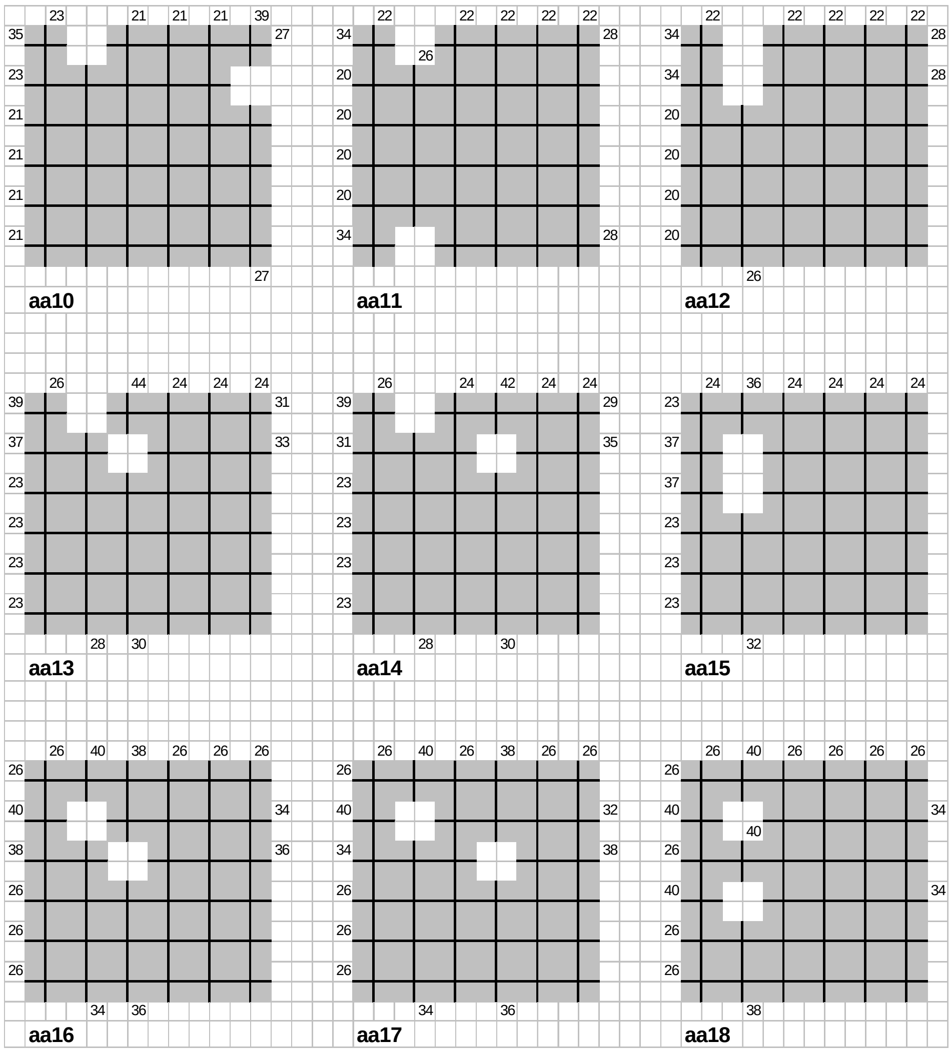


Figure 7.10 continued.

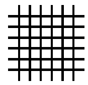
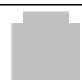
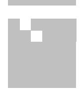
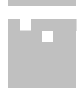
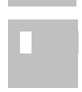
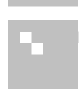
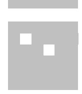
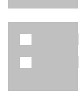
region	34 cells 136 cubicles (a)		shape analysis grid distance	shape analysis fragmentation	layout analysis number of lines	layout analysis mean MD	layout analysis mean integration
crn-crn CC	1		0.992	0.069	12	1.515	2.869
	2		0.995	0.085	12	1.515	2.835
corner-edge CE	3		1.002	0.069	12	1.515	2.869
	4		1.010	0.131	13	1.692	2.454
	5		1.008	0.154	13	1.718	2.369
crn-mid CM	6		1.030	0.240	14	1.901	2.070
	7		1.028	0.310	14	1.857	2.108
edge-edge EE	8		1.021	0.131	13	1.692	2.454
	9		1.023	0.173	14	1.846	2.212
	10		1.022	0.220	14	1.901	2.059
	11		1.022	0.235	14	1.868	2.129
edge-middle EM	12		1.042	0.235	14	1.868	2.129
	13		1.066	0.362	15	2.057	1.867
	14		1.045	0.362	15	2.019	1.900
middle-middle MM	15		1.057	0.339	15	1.981	1.962
	16		1.090	0.510	16	2.100	1.803
	17		1.067	0.526	16	2.083	1.822
	18		1.052	0.408	16	2.083	1.856

Figure 7.11: Non-equivalent ways of removing two cells from a 6x6 square floorplate and analysis of inserted grid layouts.

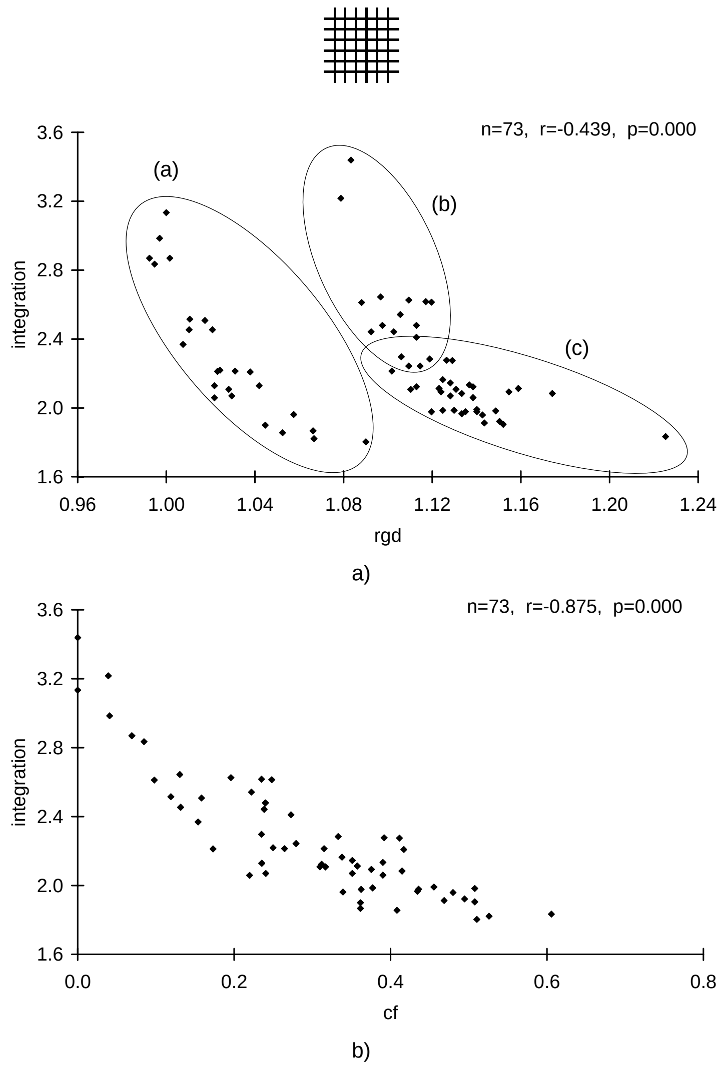


Figure 7.12: Scatterplots between layout Integration and shape indices for grid layouts inserted on basic theoretical shapes modified systematically.

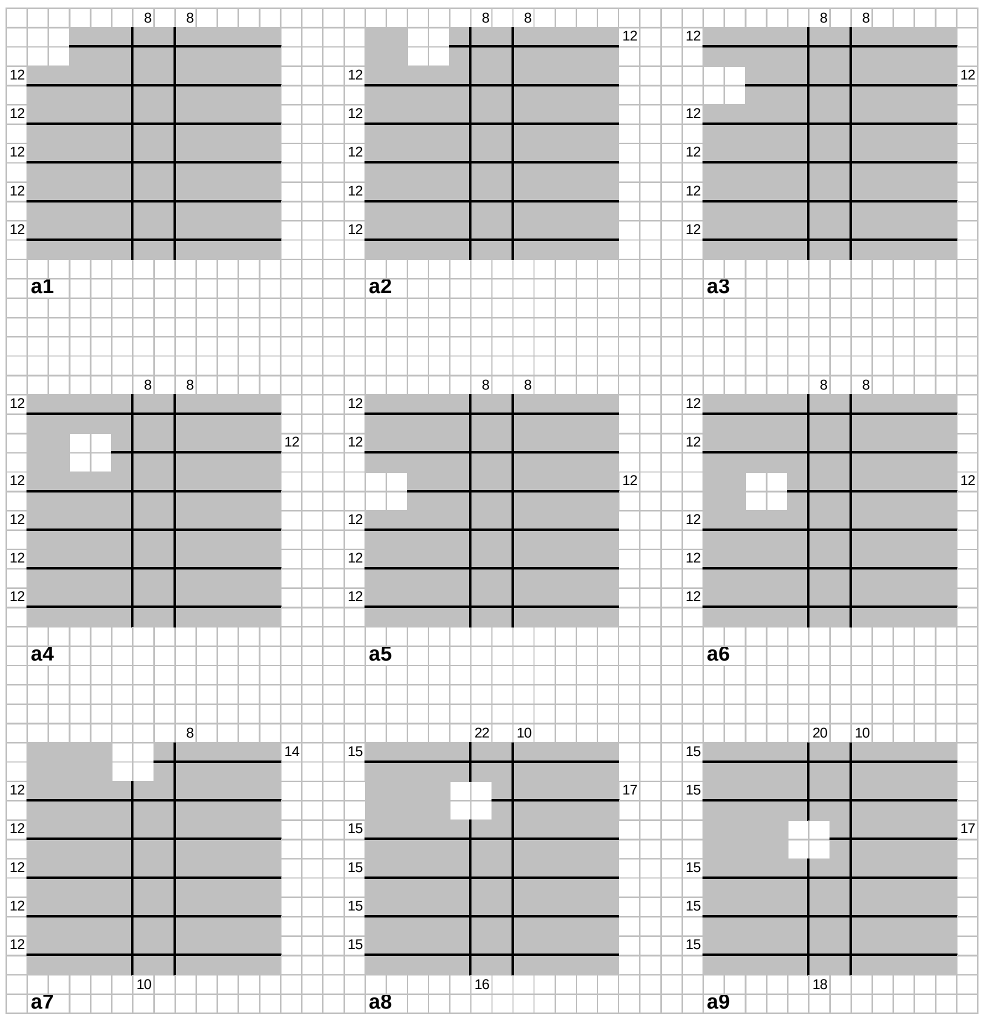


Figure 7.13: Depths values for fishbone layouts inserted on floorplates derived by removing one cell from a 6x6 square.

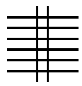
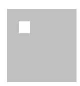
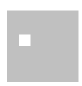
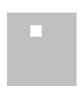
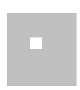
region	35 cells 140 cubicles (a)		shape analysis rgd	cf	layout analysis Number of Lines	Mean MD	Mean Integration
side S	1		0.997	0.041	8	1.571	2.758
	2		1.011	0.119	8	1.571	2.758
	3		1.011	0.119	8	1.571	2.758
	4		1.024	0.250	8	1.571	2.758
	5		1.017	0.158	8	1.571	2.758
	6		1.031	0.315	8	1.571	2.758
E	7		1.017	0.158	8	1.643	2.134
middle M	8		1.031	0.315	9	1.945	1.500
	9		1.038	0.393	9	1.945	1.487

Figure 7.14: Non-equivalent ways of removing two cells from a 6x6 square floorplate and analysis of inserted fishbone layouts.

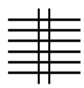
region	35 cells 140 cubicles (b v)		shape analysis rgd	 cf	layout analysis number of lines	 mean MD	 mean integration
side S	1		1.079	0.039	6	1.467	1.939
	2		1.088	0.098	6	1.467	1.939
	3		1.097	0.131	6	1.467	1.939
	4		1.109	0.196	6	1.467	1.939
	5		1.106	0.235	6	1.467	1.939
	6		1.119	0.333	6	1.467	1.939
edge E	7		1.117	0.235	6	1.473	1.600
	8		1.120	0.248	6	1.473	1.600
M	9		1.126	0.392	7	2.000	1.068
	10		1.129	0.411	7	2.000	1.068

Figure 7.15: Non-equivalent ways of removing one cell from a 9x4 oblong (b v) floorplate and analysis of inserted fishbone layouts with vertical spine.

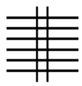
region	35 cells 140 cubicles (b h)		shape analysis rgd	cf	layout analysis number of lines	mean MD	mean integration
side S	1		1.079	0.039	11	1.673	3.770
	3		1.097	0.131	11	1.673	3.770
	4		1.109	0.196	11	1.673	3.770
	5		1.117	0.235	11	1.673	3.770
	6		1.120	0.248	11	1.673	3.770
E			1.088	0.098	11	1.709	2.936
middle M	7		1.106	0.235	12	1.924	2.035
	8		1.119	0.333	12	1.924	2.010
	9		1.126	0.392	12	1.924	1.997
	10		1.129	0.411	12	1.924	1.993

Figure 7.16: Non-equivalent ways of removing one cell from a 9x4 oblong (b h) floorplate, and analysis of inserted fishbone layouts with horizontal spine.

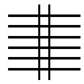
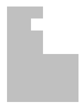
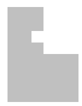
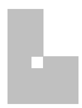
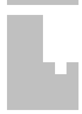
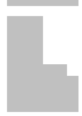
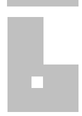
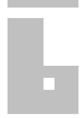
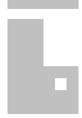
region	35 cells 140 cubicles (c v)		shape analysis rgd	cf	layout analysis number of lines	mean MD	mean integration
side S (to be continued)	1		1.103	0.238	10	1.644	3.457
	2		1.131	0.317	10	1.644	3.457
	3		1.155	0.376	10	1.644	3.457
	4		1.174	0.415	10	1.644	3.457
	5		1.225	0.606	10	1.644	3.457
	6		1.159	0.358	10	1.644	3.457
	7		1.138	0.312	10	1.644	3.457
	8		1.113	0.240	10	1.644	3.457
	9		1.152	0.508	10	1.644	3.457
	10		1.140	0.436	10	1.644	3.457
	11		1.130	0.377	10	1.644	3.457
	12		1.115	0.279	10	1.644	3.457

Figure 7.17: Non-equivalent ways of removing one cell from the 36 unit L-shape (c v) floorplate and analysis of inserted fishbone layouts with vertical spine.

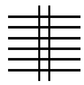
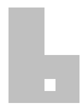
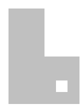
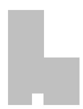
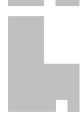
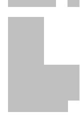
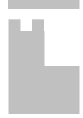
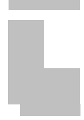
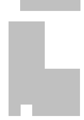
region	35 cells 140 cubicles (c v)		shape analysis rgd	 cf	layout analysis number of lines	 mean MD	 mean integration
side S (continued)	13		1.144	0.469	10	1.644	3.457
	14		1.135	0.436	10	1.644	3.457
	15		1.125	0.377	10	1.644	3.457
	16		1.109	0.279	10	1.644	3.457
	17		1.128	0.351	10	1.644	3.457
	18		1.123	0.358	10	1.644	3.457
	19		1.113	0.312	10	1.644	3.457
	20		1.098	0.240	10	1.644	3.457
edge E	21		1.092	0.238	10	1.689	2.689
	22		1.102	0.264	10	1.689	2.689
	23		1.113	0.273	10	1.689	2.689
	24		1.125	0.338	10	1.689	2.689

Figure 7.17 continued.

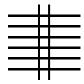
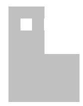
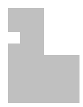
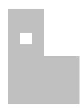
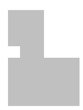
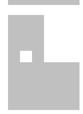
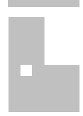
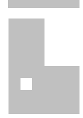
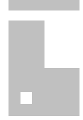
region	35 cells 140 cubicles (c v)		shape analysis rgd	 cf	layout analysis number of lines	 mean MD	 mean integration
middle M	25		1.110	0.317	11	1.927	1.870
	26		1.120	0.362	11	1.927	1.870
	27		1.124	0.376	11	1.927	1.847
	28		1.133	0.434	11	1.927	1.847
	29		1.133	0.415	11	1.927	1.838
	30		1.143	0.480	11	1.927	1.838
	31		1.138	0.390	11	1.927	1.838
	32		1.150	0.495	11	1.927	1.838
	33		1.137	0.390	11	1.927	1.847
	34		1.149	0.508	11	1.927	1.847
	35		1.128	0.351	11	1.927	1.870
	36		1.140	0.456	11	1.927	1.870

Figure 7.17 continued.

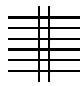
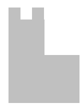
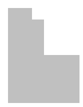
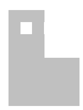
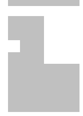
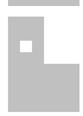
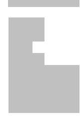
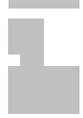
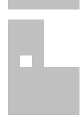
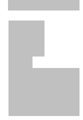
region	35 cells 140 cubicles (c h)		shape analysis rgd	cf	layout analysis number of lines	mean MD	mean integration
side S (to be continued)	1		1.092	0.238	8	1.571	2.758
	2		1.102	0.264	8	1.571	2.758
	3		1.103	0.238	8	1.571	2.758
	4		1.110	0.317	8	1.571	2.758
	5		1.120	0.362	8	1.571	2.758
	6		1.131	0.317	8	1.571	2.758
	7		1.124	0.376	8	1.571	2.758
	8		1.133	0.434	8	1.571	2.758
	9		1.155	0.376	8	1.571	2.758
	10		1.133	0.415	8	1.571	2.758
	11		1.143	0.480	8	1.571	2.758
	12		1.174	0.415	8	1.571	2.758

Figure 7.18: Non-equivalent ways of removing one cell from the 36 unit L-shape (c h) floorplate, and analysis of inserted fishbone layouts with horizontal spine.

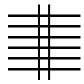
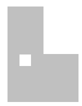
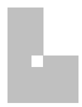
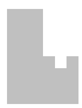
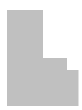
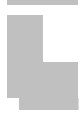
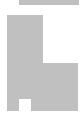
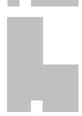
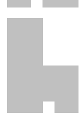
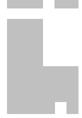
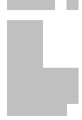
region	35 cells 140 cubicles (c h)		shape analysis grid distance	fragmentation	layout analysis number of lines	mean MD	mean integration
side S (continued)	13		1.138	0.390	8	1.571	2.758
	14		1.150	0.495	8	1.571	2.758
	15		1.225	0.606	8	1.571	2.758
	16		1.159	0.358	8	1.571	2.758
	17		1.138	0.312	8	1.571	2.758
	18		1.113	0.240	8	1.571	2.758
	19		1.113	0.273	8	1.571	2.758
	20		1.125	0.338	8	1.571	2.758
	21		1.128	0.351	8	1.571	2.758
	22		1.123	0.358	8	1.571	2.758
	23		1.113	0.312	8	1.571	2.758
	24		1.098	0.240	8	1.571	2.758

Figure 7.18 continued.

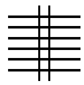
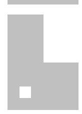
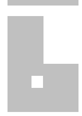
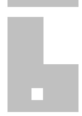
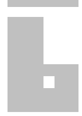
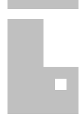
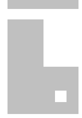
region	35 cells 140 cubicles (c h)		shape analysis grid distance	 fragmentation	layout analysis number of lines	 mean MD	 mean integration
edge E	25		1.137	0.390	8	1.643	2.134
	26		1.128	0.351	8	1.643	2.134
	27		1.109	0.279	8	1.643	2.134
	28		1.115	0.279	8	1.643	2.134
middle M	29		1.149	0.508	9	1.944	1.500
	30		1.140	0.456	9	1.944	1.500
	31		1.152	0.508	9	1.944	1.487
	32		1.144	0.469	9	1.944	1.487
	33		1.140	0.436	9	1.944	1.487
	34		1.135	0.436	9	1.944	1.487
	35		1.130	0.377	9	1.944	1.500
	36		1.125	0.377	9	1.944	1.500

Figure 7.18 continued.

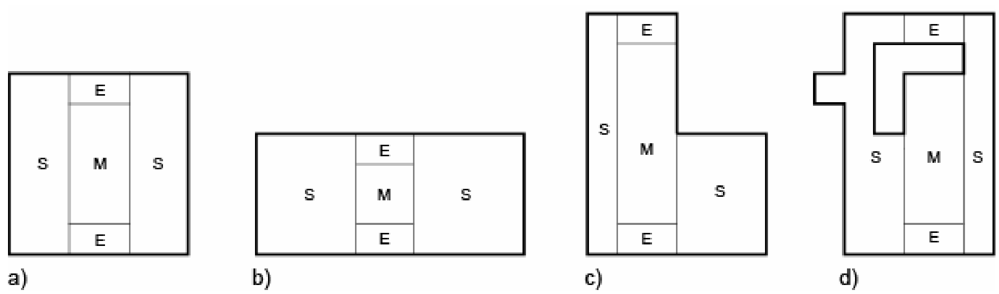
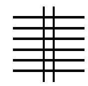
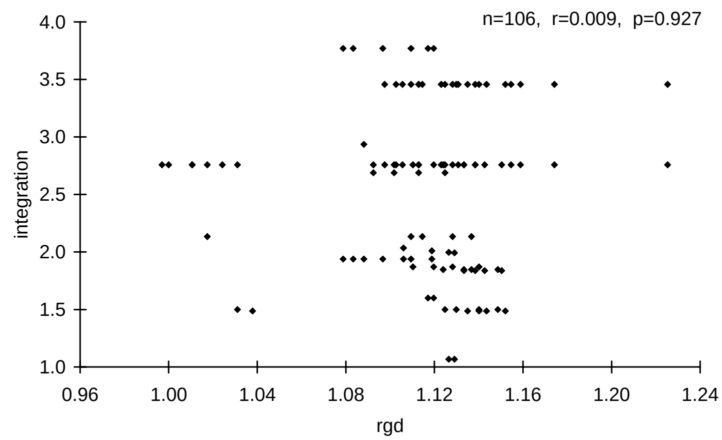
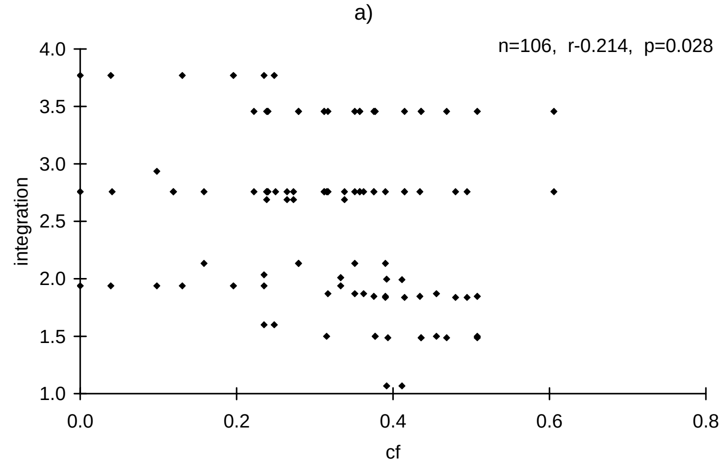


Figure 7.19: Shape regions defined according to the effect of tile removal upon the Integration of fishbone layouts with vertical spine applied to simple shapes.

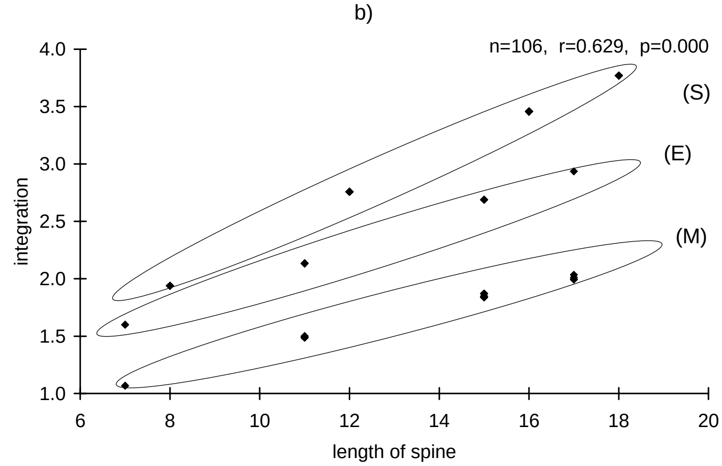




a)



b)



c)

Figure 7.20: Scatterplots between layout Integration and shape indices for fishbone layouts inserted on basic theoretical shapes modified systematically.

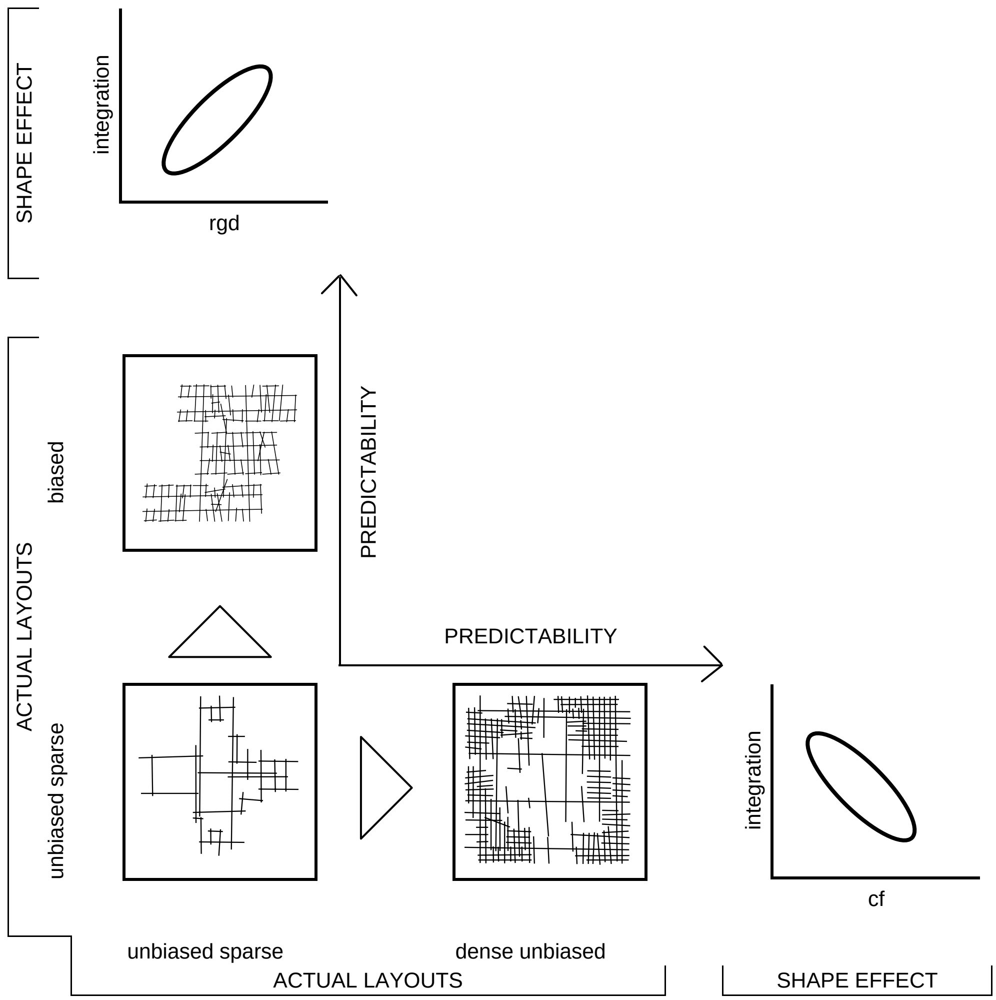


Figure 7.21: Predicting Integration of biased layouts from the rgd of floorplate shapes and Integration of unbiased dense layouts from the cf of floorplate shapes.

Chapter Eight

Testing the Hypotheses and Conclusions

8.1 Testing the Hypotheses: Hypothetical Layouts Consistently Generated in a Sample of Actual Floorplates

Grid and fishbone layouts (**figure 6.13** and **6.14**) are generated in the 25 actual floorplates corresponding to US buildings included in the sample of 50 described earlier (**figure 6.1**). This sample does not represent floorplates of office buildings in Europe, Australia and Middle East, included in the original sample. The floorplates of the 25 selected US buildings represent cases from 5 of 6 proposed floorplate types (**figure 8.1)**. A complete analysis of the non-US cases in the future may modify the findings presented here.

The grain (discussed in Appendix 7) for both types of hypothetical layouts is based on clusters of 4 workstations of about 8x8 ft and circulation width of 4 ft. Dimensions are allowed to vary slightly to fit the mullion grid or the depth from core to perimeter. In each case a circulation ring is created around the central core. Where possible, the main fishbone axis is taken through the core, across the entire available longest length of the floorplate; secondary axes branch in parallel rows either from the main axis, or from the circulation ring around the core. The grid layout is arranged in successive modules extending outwards from the circulation ring around the core in each direction. The layouts are represented with linear maps and their Integration is calculated. The grid generators are illustrated in **figure 8.2** where the hypothetical grid plan is shown on the left and its axial map is shown on the right. The fishbone generators are in shown in **figure 8.3** where hypothetical fishbone is shown in the left and its linear map on the right.

Integration is calculated for hypothetical grid layouts and hypothetical fishbone layouts consistently generated in the 25 floorplates (**table 8.1**). The correlations between the shape indices and the Integration of these layouts are shown in **figure 8.4**. For grid layouts, there exist strong and significant negative correlations between layout Integration and shape measures. Integration correlates with rgd at (r=-0.725, p=0.000), while it correlates with cf at (r=-0.860, p=0.000). Convex Fragmentation is the best predictor of the Integration of grid layouts. More convex floorplates are associated with more integrated grid layouts. For fishbone layouts, there exist strong and significant positive correlations between shape measure and layout integration (**figure 8.5**). Integration correlates with rgd at (r=0.817, p=0.000), while it correlates with cf at (r=0.653, p=.0.000). Relative Grid Distance is the best predictor of the Integration of fishbone layouts. These correlations fully demonstrate the validity of the earlier hypotheses.

The scatterplots between rgd and Integration for grid layouts and fishbone layouts exhibit peculiar splits into two clusters approximately cut by a vertical line at rgd=1.2 (**figure 8.5**). The division according to rgd=1.2 coincides with one of the yardstick values used for the classification of floorplate. Types “compact blocks external core” and “deep space small central core” have rgd<1.2, while the other four types have rgd>1.2 (**figure 5.15**). Correlations of rgd against Integration are computed for each cluster separately. Grids generated in floorplates with rgd<1.2 correlate (n=14, r=-0.623, p=0.017) and grids generated in floorplates with rgd>1.2 correlate (n=11, r=-0.628, p=0.039). These correlations are weaker and less significant than correlations for the sample considered as a whole. This demonstrates that there are no particular effects exerted by different floorplate types upon unbiased dense layouts.

For fishbones layouts generated in floorplates with rgd<1.2, the correlation between rgd and Integration is (n=14, r=0.878, p=0.000) and for rgd>1.2, the correlation is (n=11, r=0.915, p=0.000). In contrast to grids, the correlations for fishbones are significantly improved when clusters, coinciding to types of floorplates, are considered separately. This shows that the effect of floorplates on biased layouts is exerted according to different constraints according to the compactness, i.e. Relative Grid Distance, of types of floorplates.

For two types of grid and fishbone layouts alike, the lack of clustering in scatterplots of cf against Integration demonstrates that the effect of convex fragmentation is not exerted according to differences across types of floorplates.

8.2 Conclusions

The thesis formulates a theory of how characteristics of floorplate shapes affect the circulation integration in office layouts. The different longevities of the rigid shells and the flexible layouts are not only the source for the main line of inquiry but they also suggest the methodology of analysis based on experiments with a few hypothetical layouts applied into large numbers of theoretical and actual floorplates. The thesis has reached the following conclusions:

Descriptions of Shape

The thesis contributes new description of shape based on global relative characteristics of internal modular shape units according to a configurational model. These descriptions introduce metrics in the syntactic analysis of space and form. These descriptions are based on elemental human perception of space: the metric inertia associated with covering distances and the kinetic directional inertia associated with changes of directions of travel. Relative Grid Distance is a measure of compactness which compares the aggregate grid distances between all units of a shape to all other units in this shape with the aggregate distance of the square of the same area. Convex Fragmentation is a measure of convexity which gauges the extent a shape is composed of non-convex wings and regions (refer to Chapter 5). The two measures supersede issues of dealing with shapes with holes and shapes with highly jagged perimeters which are encountered by most measures of shape in geography and geometry. Unlike geometrical descriptions of shape which are based on abstract relations among discrete shape elements, the two proposed measures are founded on human perceptions of space therefore suggesting spatial descriptions of built environments suitable for research in architecture and planning and likely to correlate with behavioral aspects of space use. From a mathematical standpoint, further research is needed to prove that the two indices taken together signify a unique description of shape, similar to Bunge's theorem, i.e. there are no two different shapes that have identical values of rgd and cf taken together. At this point, trial experiments with various shapes have not refuted this claim, leaving it open to further study.

Morphological Typology of Office Buildings

The thesis contributes a new typology of office buildings based on the compactness of floorplate shapes, expressed by Relative Grid Distance, and the convexity of floorplate shapes, expressed by Convex Fragmentation. The classification includes six types of floorplates: “compact blocks external core”, “bars”, “deep space small central core”, “shallow space large central core”, “pavilions” and “wings” (refer to Chapter 5). The thesis demonstrates the effect of floorplate shapes on layout integration in congruence with the typology of office layouts: the effect of floorplates on dense layouts is more predictable for compact floorplates (refer to Section 8.1). This classification suggests further investigation on the effect of floorplate shape on various aspects of buildings, including building cost as a derivative of perimeter length, the average distance to perimeter (Shpuza, 2003) and the configuration of day-lit regions (Steadman, 2000).

Generative Principles of Primary Circulation Based on the Structure of Floorplate Shape

The analysis of shapes with circulation units according to the calculation of Convex Fragmentation reveals the existence of key spots which are regions of shape positioned at the intersection of wings composed of shape units with the lowest overlapping convex depth. Key spots guarantee the generation of the most integrating primary circulation if pairs of key spots are connected with circulation segments according to the depth rank (refer to Appendix 4). The knowledge about key spots can aid the design of office layouts by taking full advantage of the structuring potential of floorplate shapes for generating integrated layouts.

Generative Principles of Floorplate Shape Based on the Structure of Primary Circulation

Key spots also guide the process of enhancing an original circulation system into a floorplate where occupation units of shape are attached sequentially on two sides of circulation. While the criterion for achieving the most integrating solution precipitates the experiments into very theoretical shapes of little applicability for satisfying requirements of actual buildings, it is shown that the integrating effect of the circulation extends deep into the generated floor area thereby suggesting design principles for the secondary circulation in office layouts (refer to Appendix 5).

Syntactic Descriptions Based on Distribution Patterns

The thesis enhances the syntactic analysis of linear maps by investigating the distribution pattern of measures of Integration, Mean Depth, Connectivity and Relative Line Length. The statistical index of skewness is applied to these measures to gauge the degree of bias in layouts and has provided the foundation for formulating a new typology of office layouts (refer to Chapter 6).

Morphological Typology of Office Layouts

The thesis proposes three types of office layout based on the density and connectivity bias of linear representations of layout circulation: the “biased” layouts represent cases with low density of intersection of axial lines and high connectivity bias due to a few lines connecting many secondary lines; the “unbiased sparse” layouts represent elementary and simple systems where a few lines connect to each other without noticeable differentiation; “unbiased dense” layouts represent dense and unbiased systems of bürolandschaft layouts and dense orthogonal open plan offices. This classification coincides with notable differences among layout integration, where the unbiased sparse layouts are the least integrated. This indicates two principal directions for increasing integration in office layouts: increasing the density of intersections and increasing the connectivity bias so that a few lines act as powerful integration spines (refer to Chapter 6). These principles suggest generative concepts for designing office layouts in conjunction with affinities between types of layouts and types of shells. This classification pioneers the syntactic typologies of buildings since space syntax studies to date have only addressed classifications of urban environments.

Systematic Relationship between 2D Structures with 2D Components and 2D Structures with 1D Components

The experiments with theoretical shapes and hypothetical layouts demonstrate systematic relationships between two-dimensional entities of shapes and one-dimensional entities of layouts: the effect of shapes on layouts is exerted via shape-regions which are direct ramifications of shape perimeter. This effect is strong and predictable for uniform and undifferentiated layouts, while it is not predictable for biased and irregular layouts (refer to Chapter 7).

The Effect of Floorplate Shapes on Layout Integration

Floorplate shapes influence global properties of internal layouts which are important from the points of view of function and cognition - integration affects not only the flow of movement, communication and awareness as a by-product of movement, but also spatial orientation and wayfinding. In this way it is possible to complement models of office space that emphasize more local properties, or properties associated with metric distance.

The effect of floorplates is evident in two levels: First, the effect of floorplate shapes upon layouts is more evident for layouts with high density and low differentiation and for layouts which are highly structured and differentiated due to a few strong primary circulation corridors. Accordingly, more compact floorplates are associated with greater Integration of dense and unbiased layouts and with lesser Integration of biased layouts. Second, the effect of floorplates upon Integration of layout circulation is more predictable for floorplates which are compact, have external cores or have smaller and fewer internal cores (refer to Section 8.1). These findings suggest the possibility of proposing new affinities between office shells and office layouts based upon the configuration and the metrics of floorplate shapes and the degrees of bias and density of office layouts.

Affinities between Office Floorplates and Layouts

The thesis suggests that the relationship between floorplate shape and interior layout is mediated by the generative principle applied to the generation of the layout. Fishbone and grid layouts, for example, are affected by floorplate shape not merely in different but actually in opposite ways. This has implications for future work. More refined models of the impact of floorplate shape upon layout must be developed within the parameters of a particular set of generative principles.

As a corollary of the above, the study points to an underlying congruence between a morphological typology of layouts (which distinguishes between the fishbone and the grid as alternative principles for increasing integration) and a morphological typology of shapes (which distinguishes between more compact and convexly unified shapes and shapes with a clear differentiation of wings).

Distinction between Constraint and Determination

The study highlights the distinction between constraint and determination. Floorplate shapes exercise underlying constraints upon the Integration of interior layouts but they do not determine it. This is highlighted by the difference between the strength of correlations between floorplate shapes and internal integration depending on whether we insert hypothetical layouts in actual floorplate shapes or study the actual layouts that are accommodated in these floorplate shapes at some point in the buildings life. Actual layouts bear the influence of factors ranging from design program to design approach. The effect of shape as compared to such other factors becomes statistically less powerful.

Organizations that manage or evaluate a large stock of buildings could use the proposed measures of floorplate shapes in order to enrich the early evaluation of the suitability of different buildings for different kinds of layouts. These concepts support sustainable solutions of buildings able to suit changes. At the same time, the thesis suggests that individual designers working with particular programs have considerable freedom to work within the constraints exercised by shape, especially when directionally unbiased or sparsely connected layouts are involved.

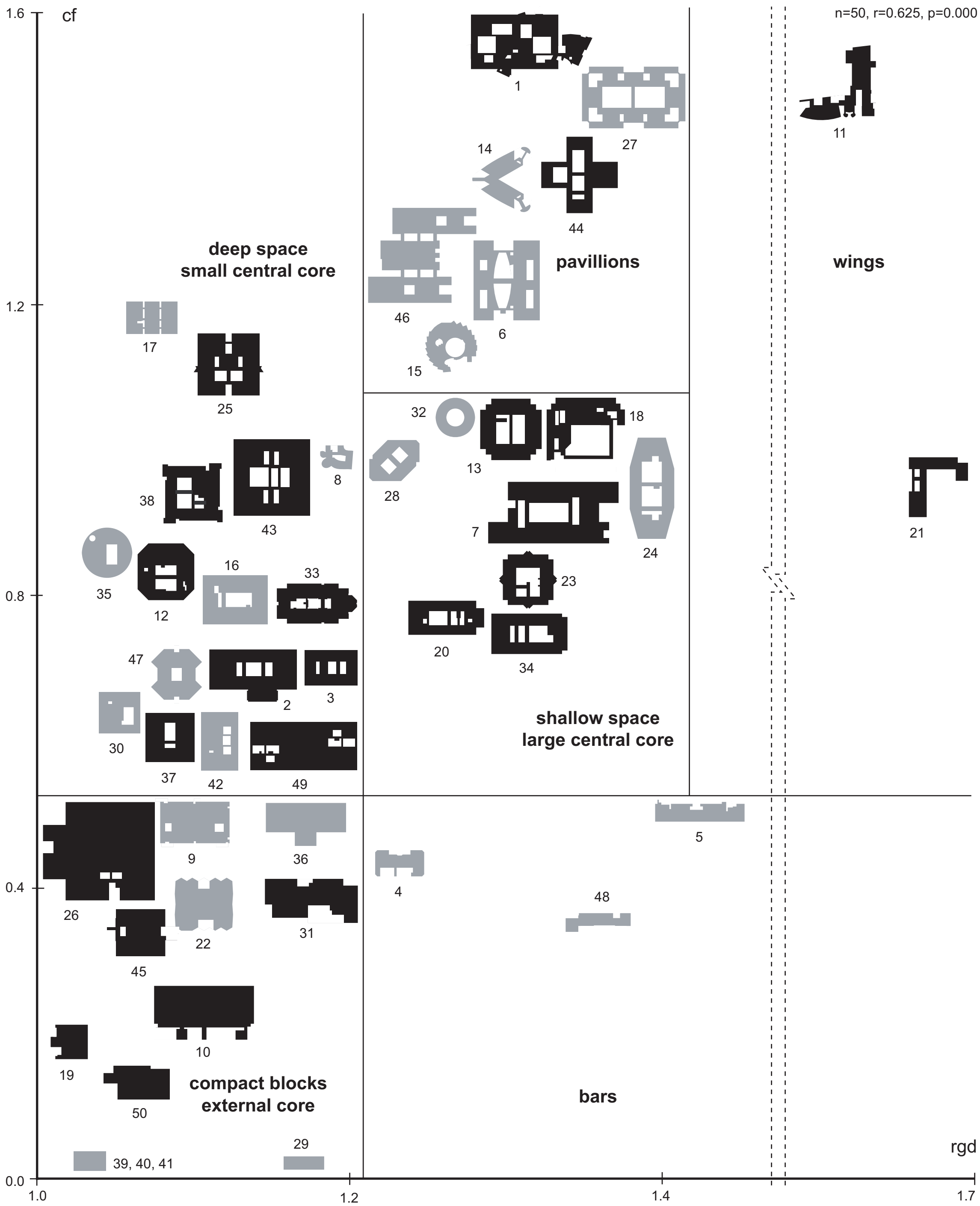


Figure 8.1: Twenty five floorplates of US buildings selected for generating hypothetical grid and fishbone layouts, highlighted in black, compared to the rest of the sample, shown in gray.

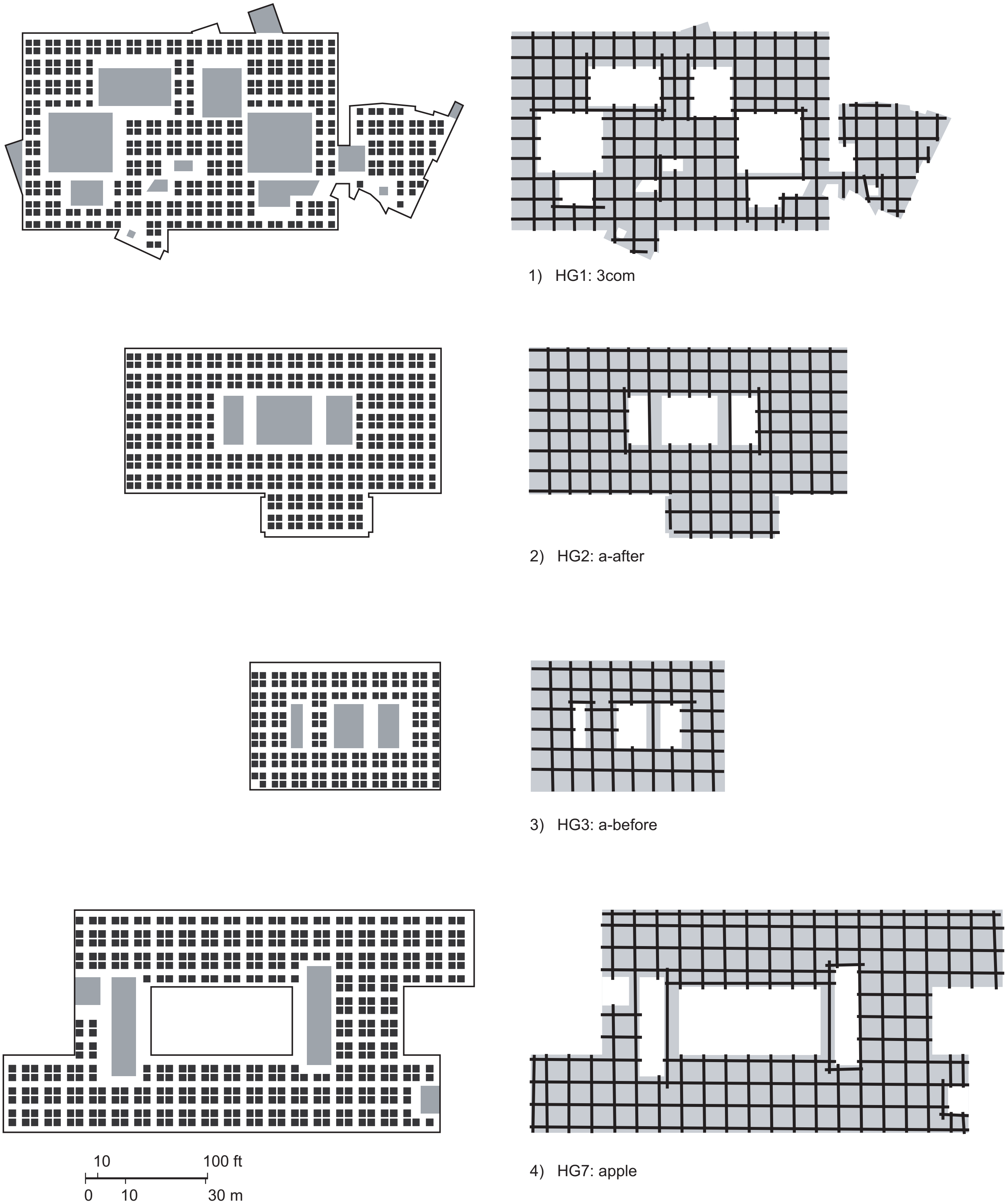
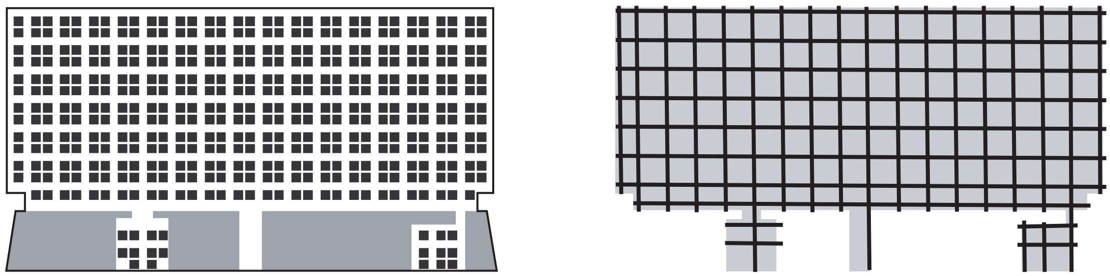
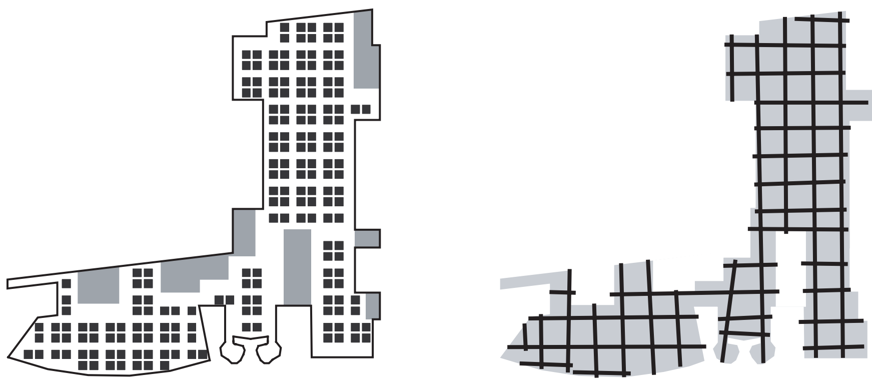


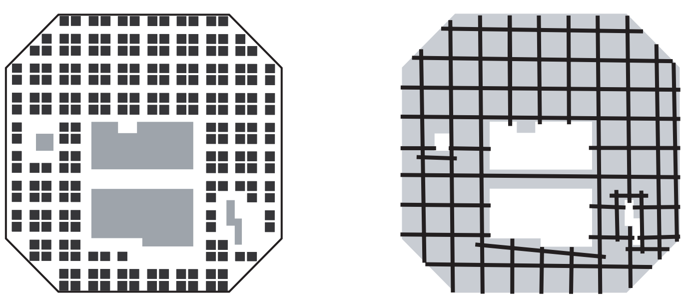
Figure 8.2: Hypothetical grid layouts generated into actual floorplates corresponding to US buildings (HG1 to HG7).



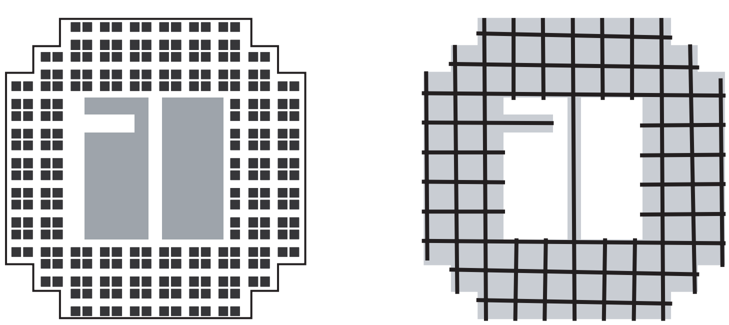
5) HG10: chase



6) HG11: chiat-ca

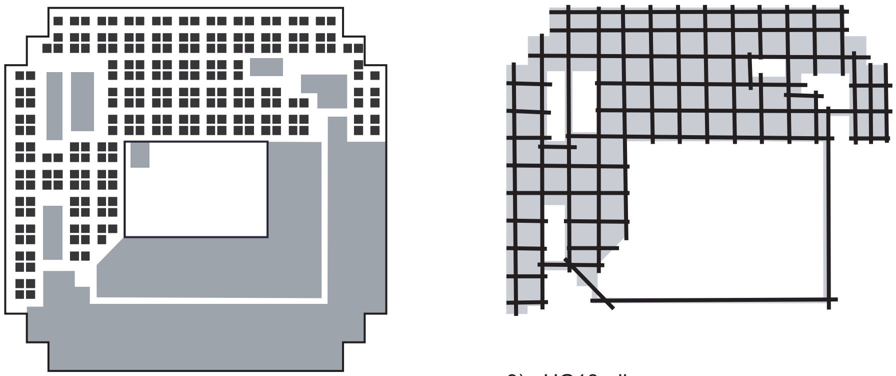


7) HG12: chiat-ny

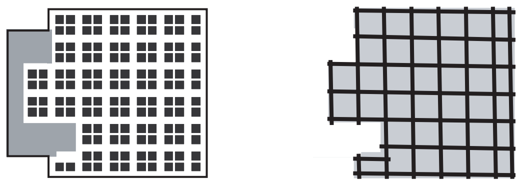


8) HG13: citicorp

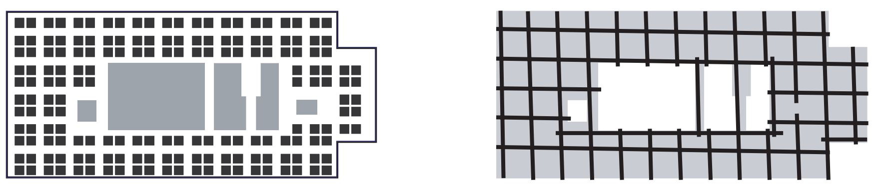
Figure 8.2 continued: (HG10 to HG13).



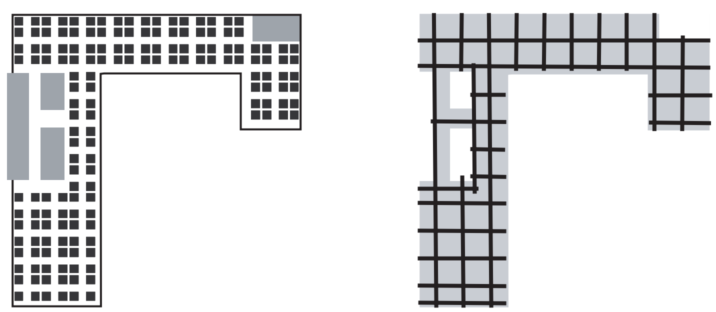
9) HG18: discovery



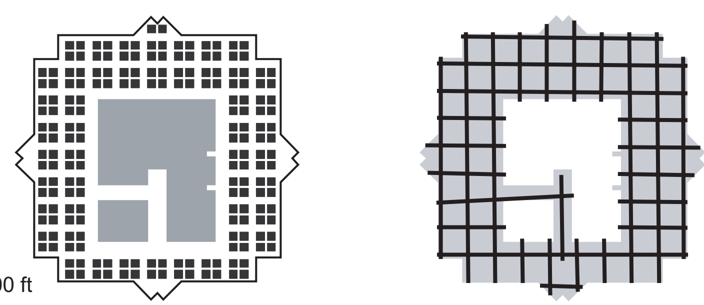
10) HG19: dupont



11) HG20: equitable

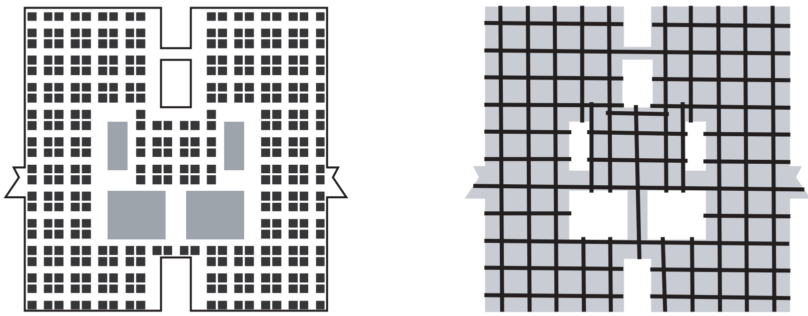


12) HG21: ford-f

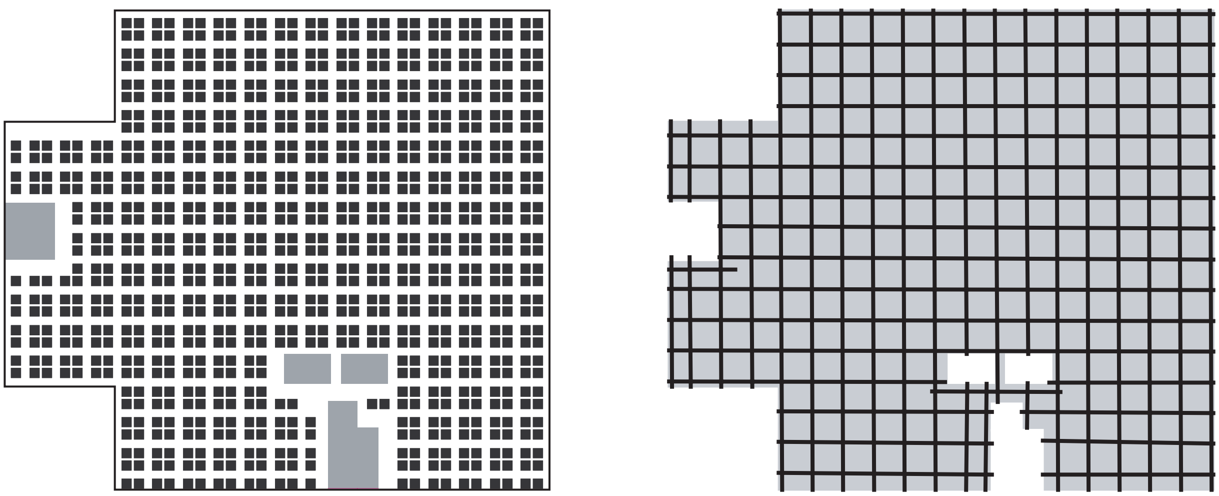


13) HG23: fx

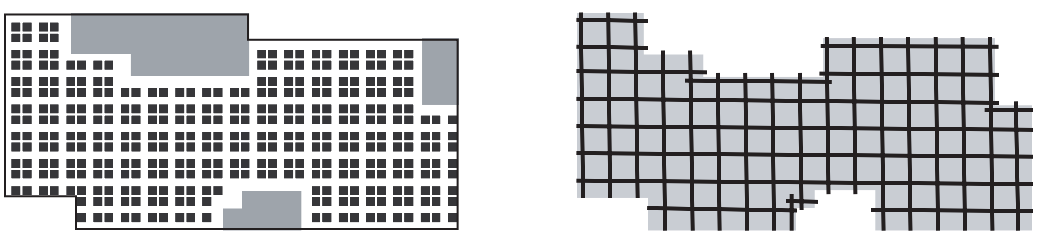
Figure 8.2 continued: (HG18 to HG23).



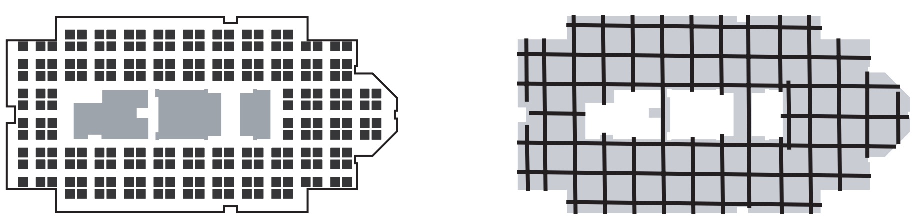
14) HG25: hoffmann



15) HG26: ibm-cranford



16) HG31: kodak



17) HG33: leo

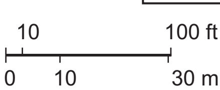
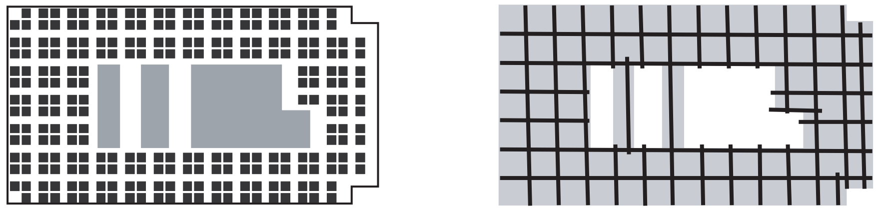
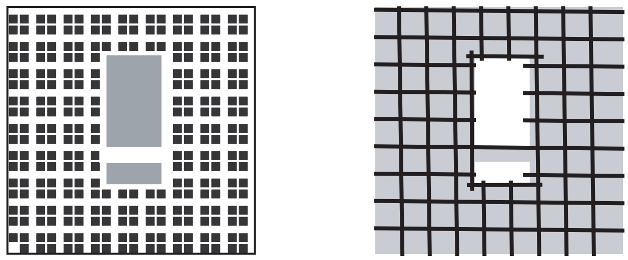


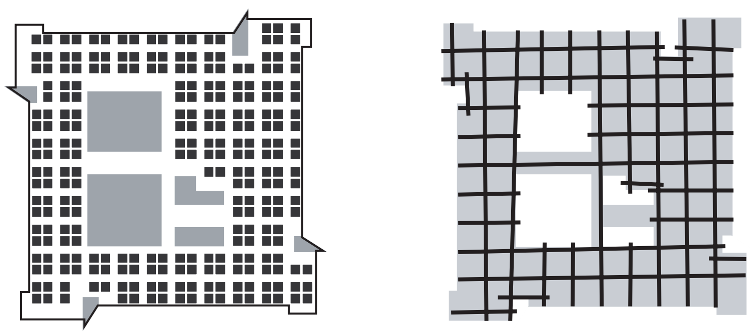
Figure 8.2 continued: (HG25 to HG33).



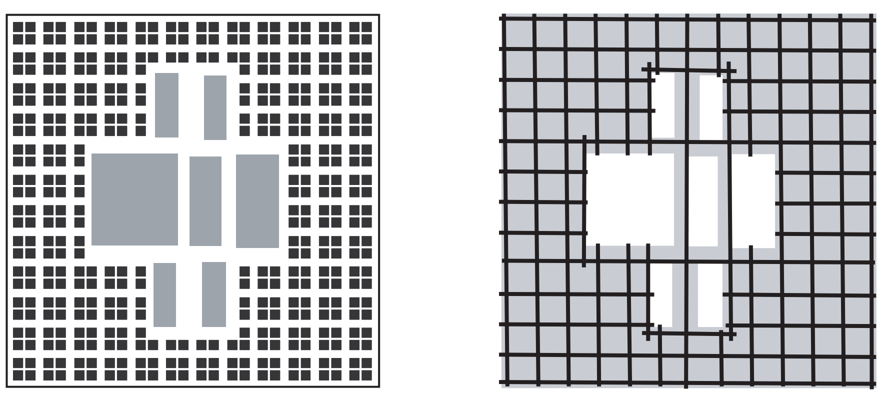
18) HG34: lowe



19) HG37: mgic

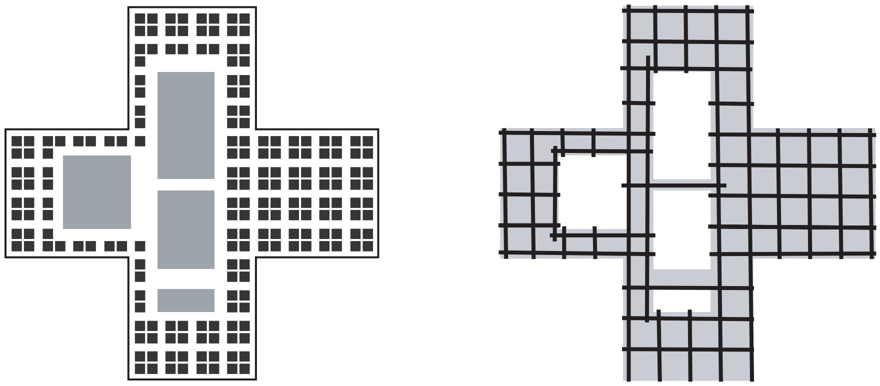


20) HG38: nickelodeon

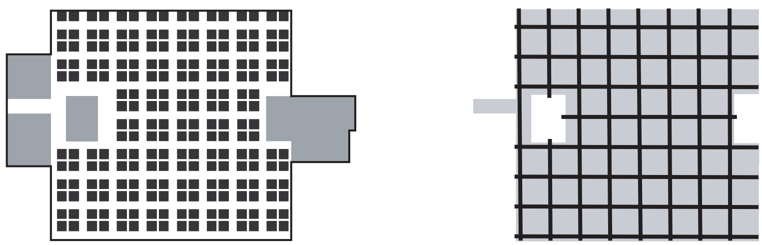


21) HG43: sears-40

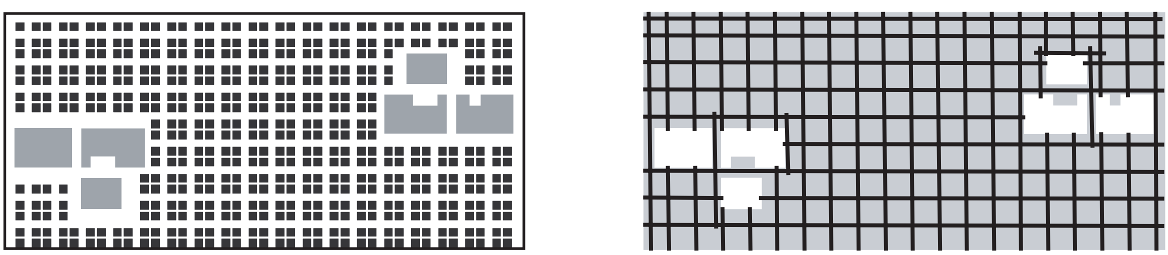
Figure 8.2 continued: (HG34 to HG43).



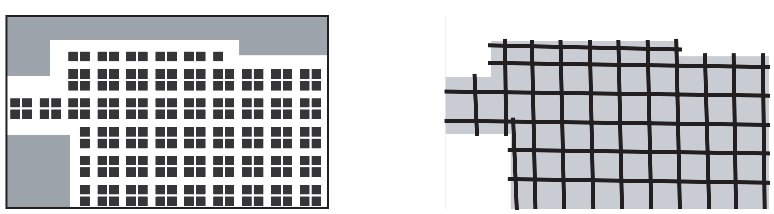
22) HG44: sears-70



23) HG45: steelcase

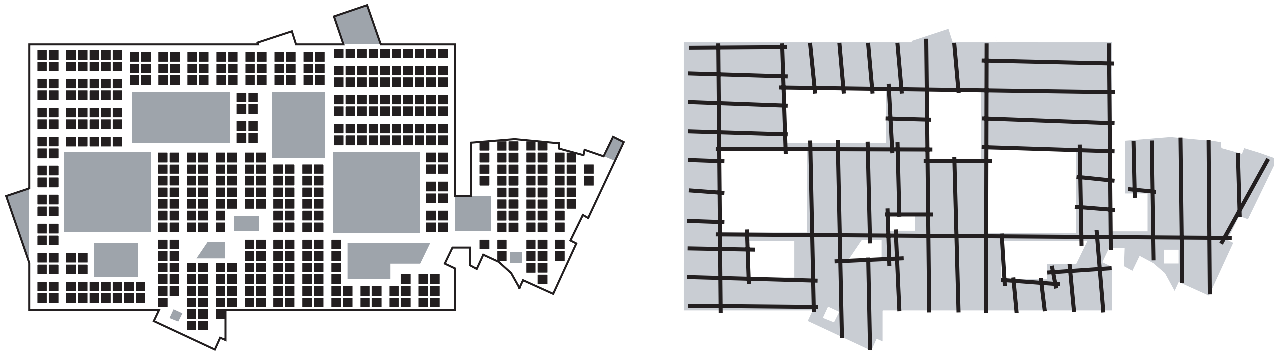


24) HG49: weyer

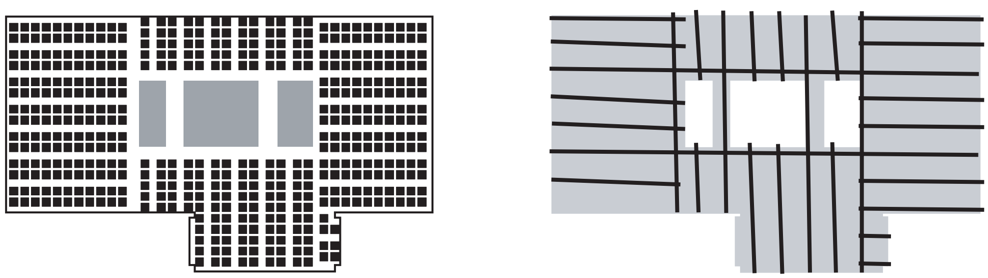


25) HG50: wma

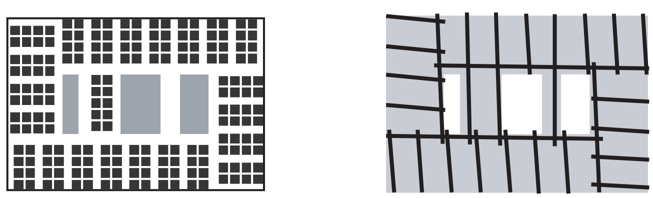
Figure 8.2 continued: (HG44 to HG50).



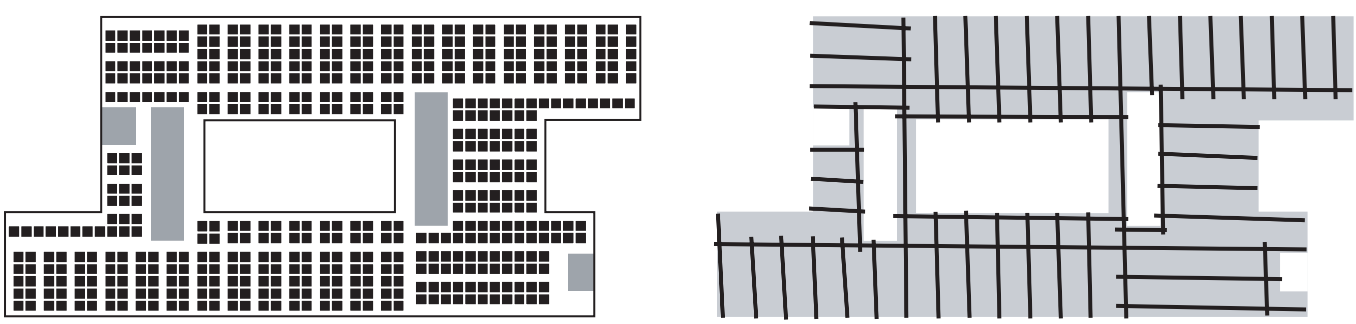
1) HF1: 3com

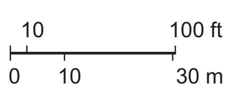


2) HF2: a-after



3) HF3: a-before





4) HF7: apple

Figure 8.3: Hypothetical fishbone layouts generated into actual floorplates corresponding to US buildings (HF1 to HF7).

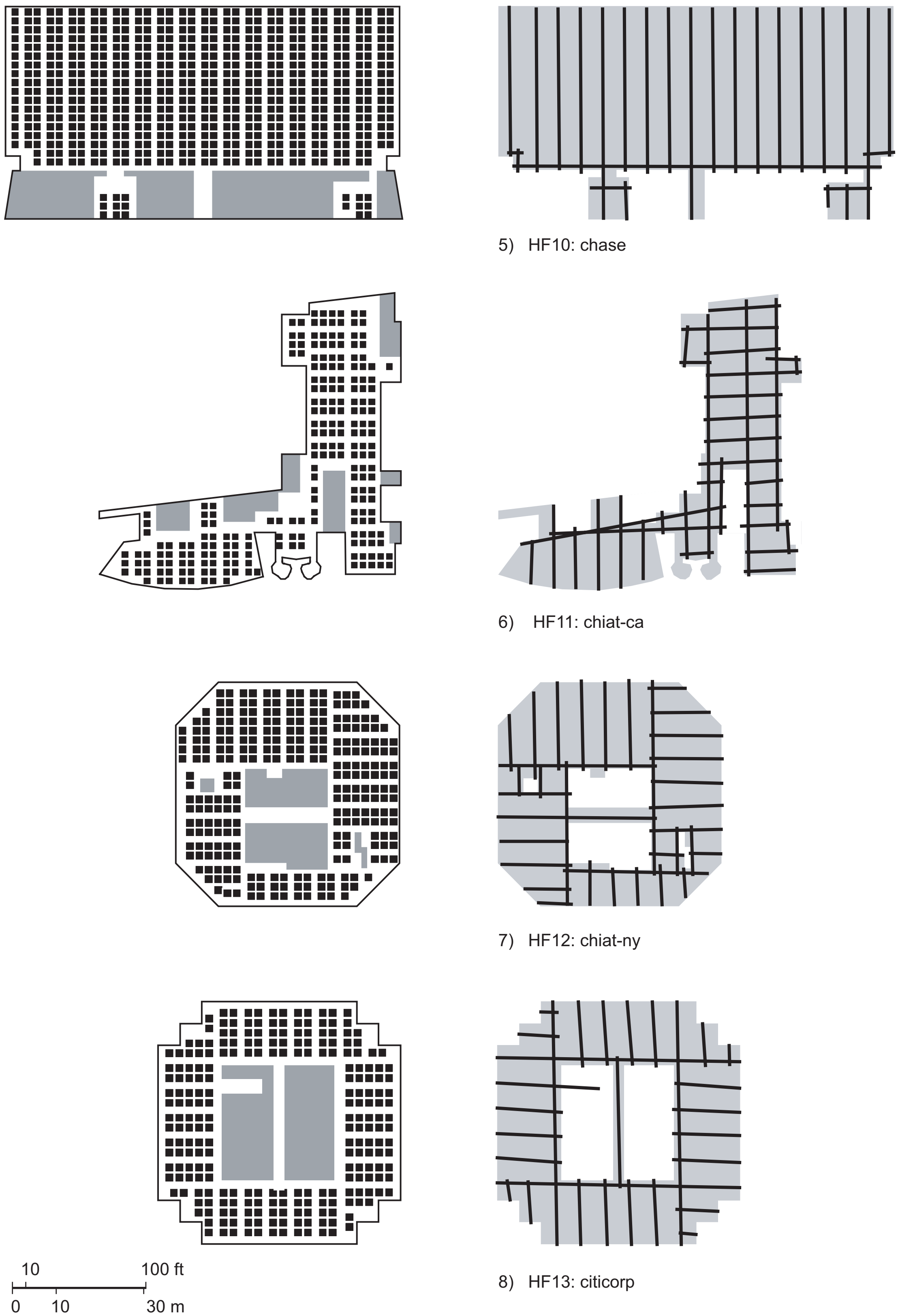


Figure 8.3 continued: (HF10 to HF13).

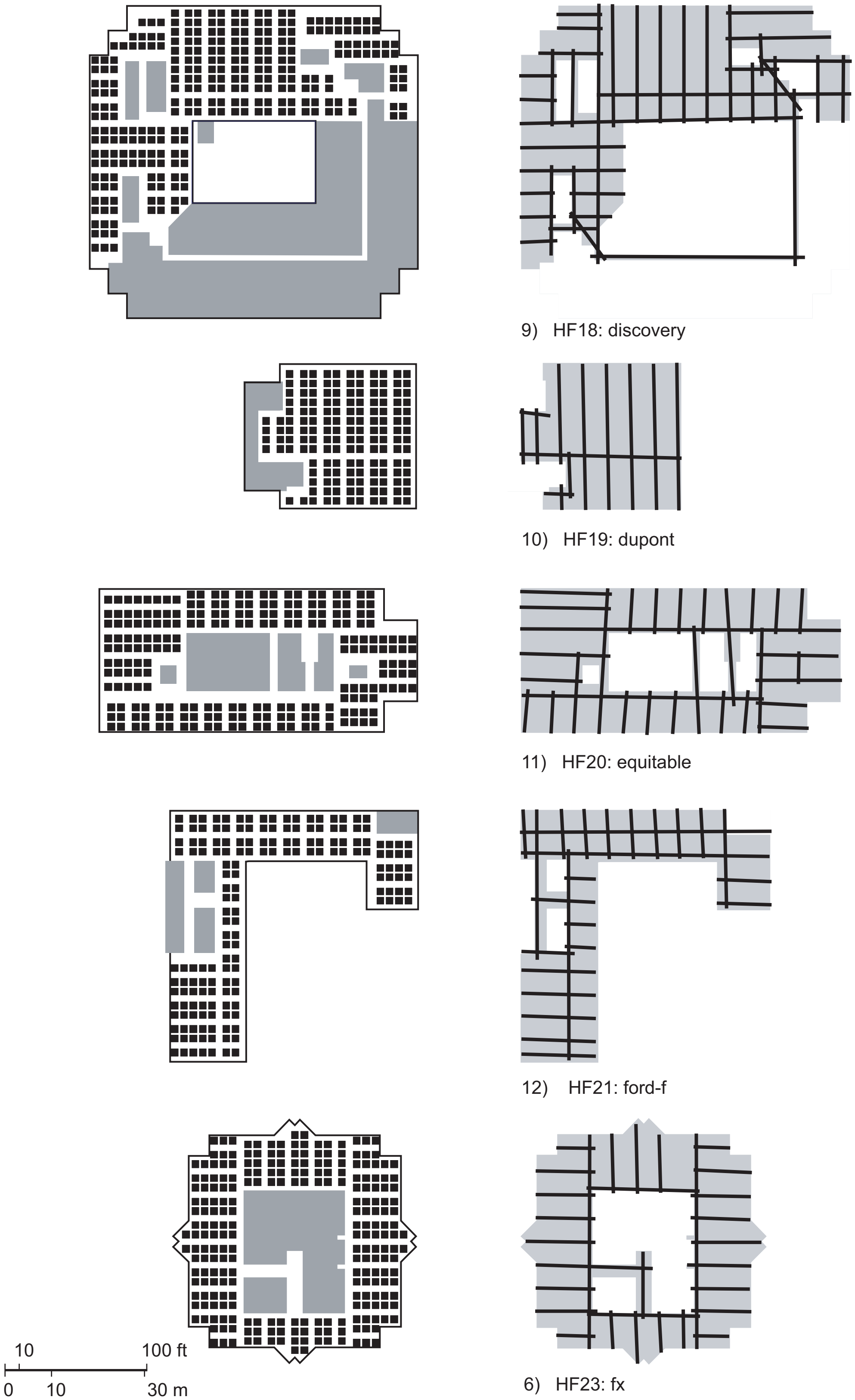
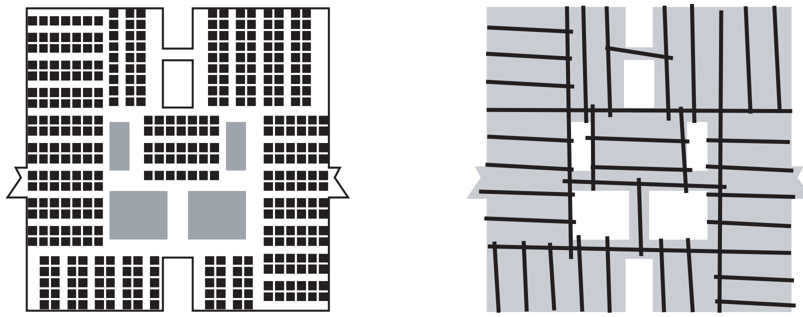
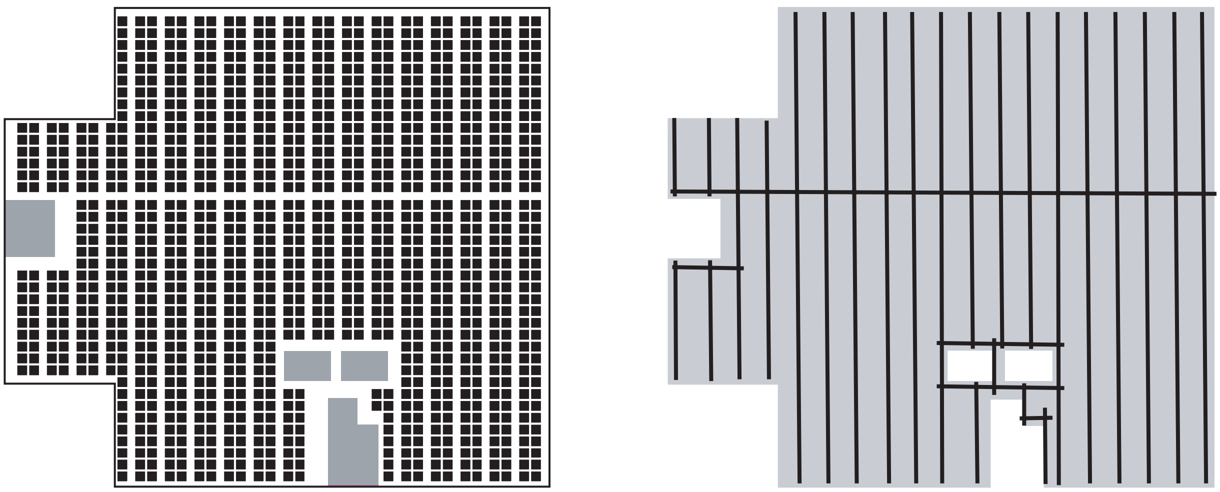


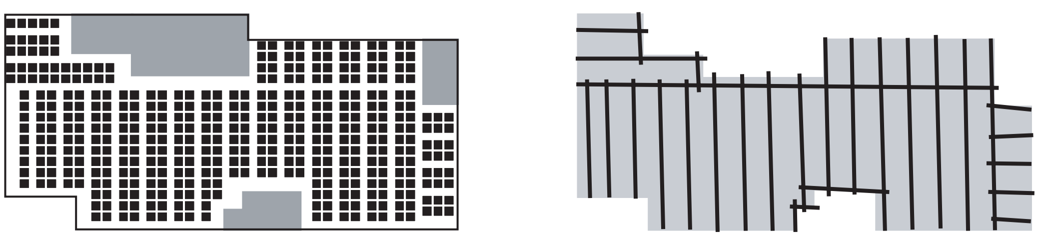
Figure 8.3 continued: (HF18 to HF23).



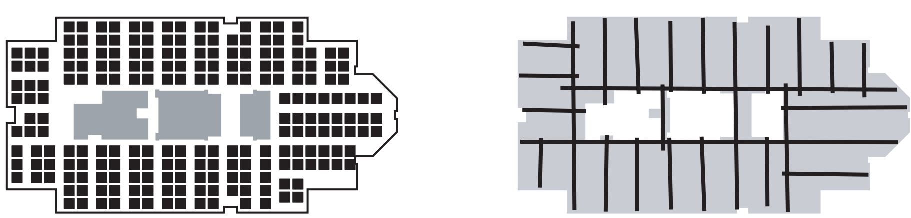
14) HF25: hoffmann

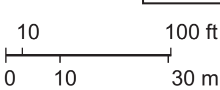


15) HF26: ibm-cranford



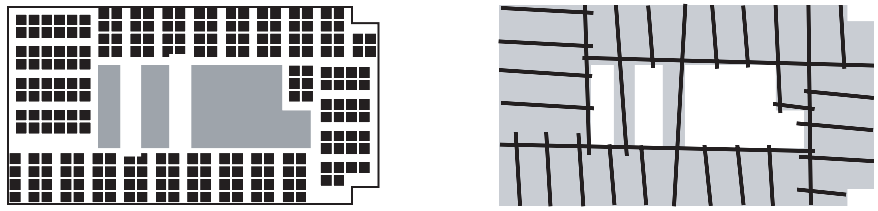
16) HF31: kodak



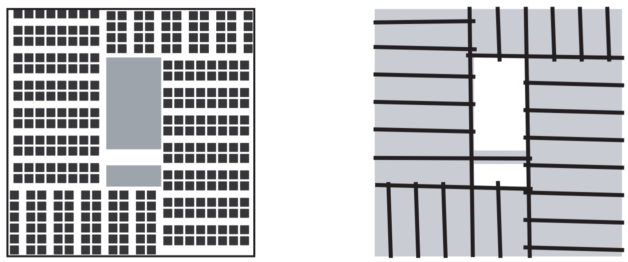


17) HF33: leo

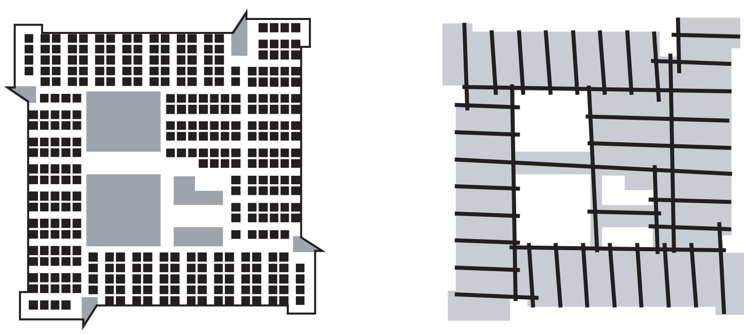
Figure 8.3 continued: (HF25 to HF33).



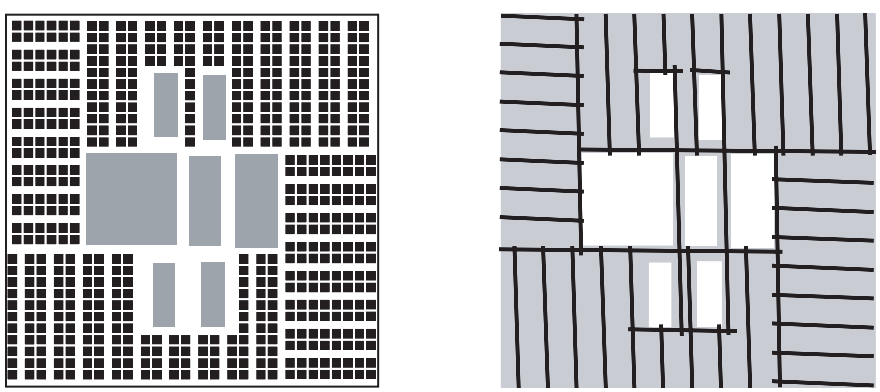
18) HF34: lowe



19) HF37: mgic

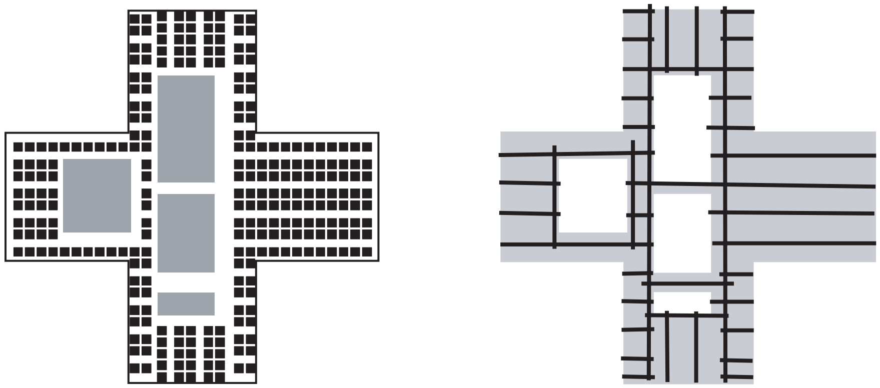


20) HF38: nickelodeon

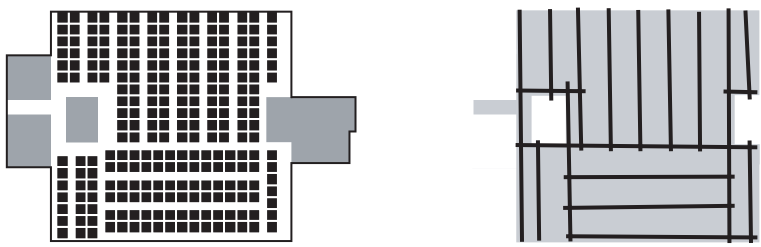


21) HF43: sears-40

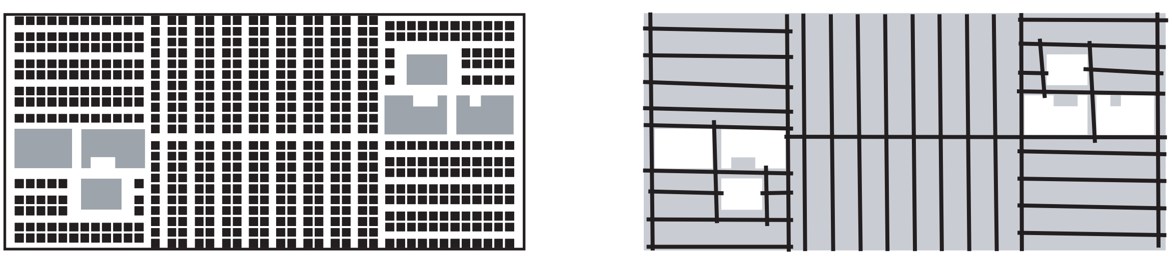
Figure 8.3 continued: (HF34 to HF43).



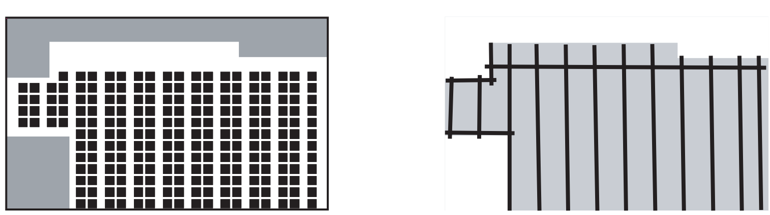
22) HF44: sears-70



23) HF45: steelcase



24) HF49: weyer



25) HF50: wma

Figure 8.3 continued: (HF44 to HF50).

Table 8.1: Integration of hypothetical grid layouts and hypothetical fishbone layouts generated into 25 actual floorplates.

	name	hypothetical grid		hypothetical fishbone	
		layout	integration	layout	integration
1	F1: 3com	HG1	1.817	HF1	1.585
2	F2: a-after	HG2	2.467	HF2	1.547
3	F3: a-before	HG3	1.977	HF3	1.610
4	F7: apple	HG7	2.199	HF7	1.613
5	F10: chase	HG10	3.076	HF10	1.523
6	F11: chiat-ca	HG11	1.223	HF11	1.724
7	F12: chiat-ny	HG12	1.801	HF12	1.593
8	F13: citicorp	HG13	2.095	HF13	1.539
9	F18: discovery	HG18	1.875	HF18	1.579
10	F19: dupont	HG19	2.600	HF19	1.430
11	F20: equitable	HG20	2.012	HF20	1.530
12	F21: ford-f	HG21	1.878	HF21	1.710
13	F23: fx	HG23	1.904	HF23	1.529
14	F25: hoffmann	HG25	2.007	HF25	1.570
15	F26: ibm-cranford	HG26	3.081	HF26	1.483
16	F31: kodak	HG31	2.481	HF31	1.583
17	F33: leo	HG33	2.103	HF33	1.561
18	F34: lowe	HG34	2.103	HF34	1.594
19	F37: mgic	HG37	2.170	HF37	1.488
20	F38: nickelodeon	HG38	1.983	HF38	1.610
21	F43: sears-40	HG43	2.345	HF43	1.620
22	F44: sears-70	HG44	1.555	HF44	1.581
23	F45: steelcase	HG45	2.688	HF45	1.484
24	F49: weyer	HG49	2.583	HF49	1.510
25	F50: wma	HG50	3.042	HF50	1.504

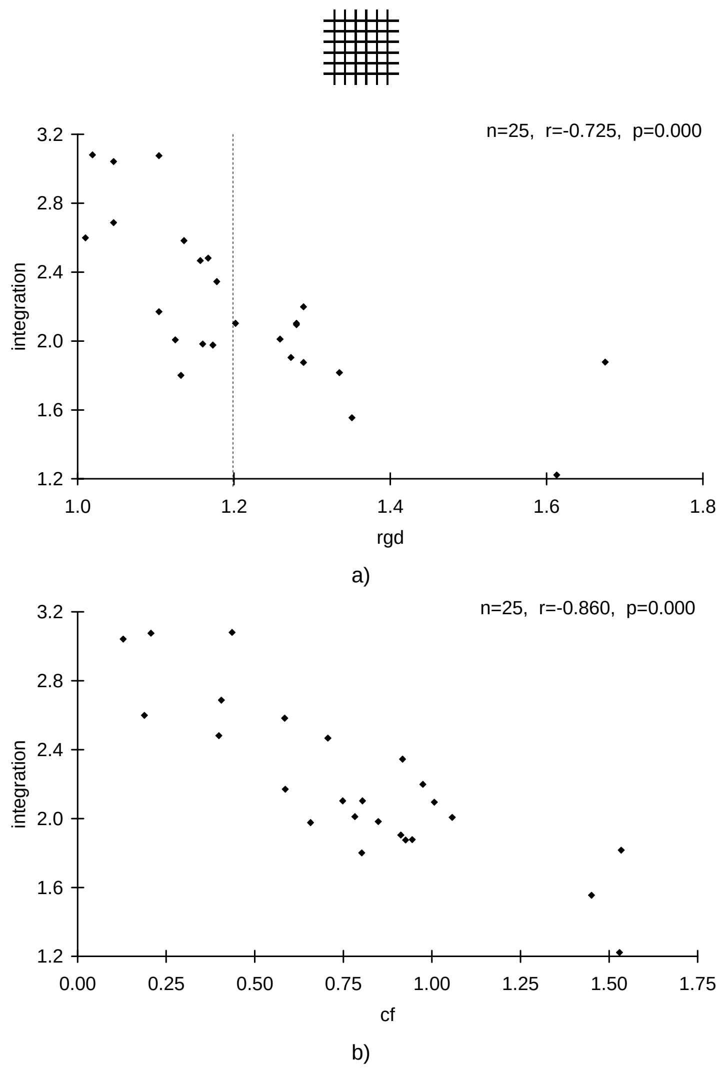


Figure 8.4: Integration of grid layouts plotted against shape measures generated on a sample of actual floorplates.

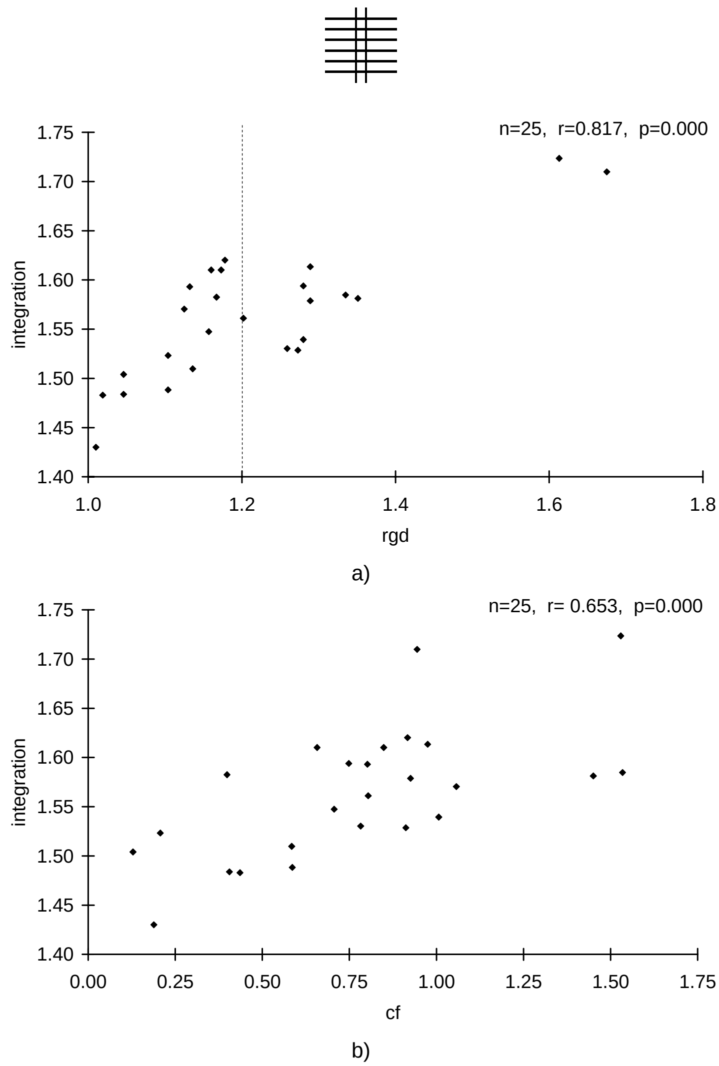


Figure 8.5: Integration of fishbone layouts plotted against shape measures generated on a sample of actual floorplates.

Appendices

Appendix 1 The Sample of Office Layouts and Floorplates

The sample includes 50 office layouts from the period between 1960s to the present and their corresponding shells from 1930s to the present (**table 5.2**). The choice is aimed at including the maximum variety of published designs within the framework of “best practice” from architecture, planning and interior design. This section gives a basic description and general data for each case, including client, building name and location, shell architect, year of completion of the shell, layout architect, year of completion of the layout, gross and net floor areas in square feet, and the source of publication. In addition, a brief description has sought to unravel key characteristics of shells and layouts. As to shells, the focus is given to shape features of the usable area, characteristics of perimeter, location of cores and the nature of column grids. These descriptions are therefore aimed at the configuration features of number of wings, existence of atria, elongation, curvature, and alignment of columns, as well as metrics of distances from core to perimeter, size of area, dimension of columns grid, and the size of floorplate bays. Layout descriptions address the circulation structure, in configurational terms and taken as a whole, as affected by designers’ choices for cellular versus open-plan workstations, clustering into different sizes of workstation groups, alignments to certain directions, and the relationship between primary and secondary circulation paths.

1

client	3com Corporation
building name | location	Santa Clara, CA
shell architects | year	STUDIOS Architecture | 1996
layout architects | year	STUDIOS Architecture | 1996
floor area in sq ft - gross | net	50,100 | 38,700
source	(Myerson & Ross, 1999), (Betsky, 1996b)

In contrast to the organic shape of the first level, the floorplate shape of the second level in consideration consists of a 260x160 ft rectangle to which a fan-shaped wing and four smaller peripheral cores are attached at a 20 degree rotation (**figure 6.1-1**). The rectangular region is punctured by six separated internal cores, and a grid of columns at 20x40 ft bays. The layout is arranged along a racetrack primary circulation with regimented 6’ 6” cubicles arranged back to back in groups of four, six and eight according to a perfect orthogonal grid.

2

client	Andersen Worldwide
building name | location	One Illinois Center | Chicago, IL
shell architects | year	Mies Van der Rohe | 1970
layout architects | year	DEGW, Skidmore Owings & Merrill | 1996
floor area in sq ft - gross | net	34,550 | 31,200
source	(Duffy & Powell, 1997), (Duffy et al., 1998)

The usable area of this Mies floorplate has a depth of 40 ft and is located around an elongated central core (**figure 6.1-2**). One side of the plan is enhanced with a protrusion which results on a 75 ft deep space. Groups of 2x4 open-plan workspaces are placed perpendicular to the racetrack primary circulation forming secondary branches according to a fishbone configuration. Groups are separated by each other by islands of cellular meeting rooms or by filing cabinets. Four larger conference rooms occupy the four corners of the 260x120 ft rectangle. The two long corridors abutting the core have gained a commanding role for organizing the layout by stretching from one side of the plan to the other while connecting to almost all other circulation paths.

3

client	Andersen Worldwide
building name | location	unknown | Chicago, IL
shell architects | year	unknown
layout architects | year	unknown
floor area in sq ft - gross | net	16,350 | 14,100
source	(Duffy et al., 1998)

The central core in this rectangular floorplate leaves a 35 ft deep space on four sides (**figure 6.1-3**). The layout is organized based on a racetrack primary circulation which divides the cellular offices placed along the perimeter and clusters of two, three or four open plan workstations located near the core.

4

client	Allen & Overy
building name | location	Rockefeller Center | New York, NY
shell architects | year	The Associated Architects | 1938
layout architects | year	The Switzer Group | 1998
floor area in sq ft - gross | net	10,500 | 8,300
source	(Slatin, 2001)

The core is attached to one side of the perimeter, while the usable area has a configuration of a double T (**figure 6.1-4**). The layout is typical for a law firm having cellular spaces along the naturally lit perimeter, and conference rooms and secretarial workstation in the center. Offset 15 ft inward from perimeter, the circulation has resulted in a simple rectilinear grid with three major lines starting from the core and three main rings attached to it.

5

client	Arthur Andersen Business Consulting
building name | location	unknown | London, UK
shell architects | year	unknown
layout architects | year	BDG McColl, BDG Workfutures | 1997
floor area in sq ft - gross | net	14,900 | 12,700
source	(Myerson & Ross, 1999)

The floorplate is distinctly elongated having a length of 270 ft and a depth of 54 ft. Three separate cores abutting the rear wall create four bays of spaces while leaving a continuous space with the width of a column bay along the front wall (**figure 6.1-5)**. A café at the entrance from the elevator extends in two sides with informal meeting spaces. The main curving circulation is developed along the front wall dividing the collaborative workplace from the open-plan concentrated workstations.

6

client	Apicorp
building name | location	Al Khobar, Saudi Arabia
shell architects | year	DEGW, Ove Arup & Associates | 1996
layout architects | year	DEGW | 1996
floor area in sq ft - gross | net	39,100 | 33,100
source	(Duffy et al., 1998), (Slessor, 1998)

The plan is organized in two pavilions separated by a central atrium. Each pavilion is developed around four smaller courts (**figure 6.1-6**). Three external cores are located in outer sides of the pavilions for solar shielding. The layout is mostly cellular and is organized based on a clear circulation grid with corridors running across the floorplate between external staircases.

7

client	Apple Computer Inc.
building name | location	De Anza 3 | Cupertino, CA
shell architects | year	unknown | 1980
layout architects | year	Gensler | unknown
floor area in sq ft - gross | net	53,000 | 48,900
source	(Iannacci, 1998)

The building surrounds an open courtyard, while the two longer wings extend in opposite directions giving the floorplate an S-shape configuration (**figure 6.1-7**). The layout for the Networking and Communications Group is organized around two main racetrack circulations: the inner one surrounds the courtyard; the outer one is located 10 ft deep from three sides of perimeter. The two primary rings connect to each other via four diagonal paths that run through four circular hubs. Workspaces with high partitions are grouped into clusters of 2x4, 2x3 and 2x2 placed according to an orthogonal grid.

8

client	Andersen Consulting, Accenture
building name | location	Nationale Nederlanden | Prague, Czech Republic
shell architects | year	Frank O. Gehry and Milunić | 1996
layout architects | year	Eva Jirična Architects | 1996
floor area in sq ft - gross | net	5,700 | 4,450
source	(Myerson & Ross, 1999), (Ragheb, et al., 2001), (Gehry, 1996)

The location of the building at a street corner has produced a floorplate shape that can be best described as a quarter doughnut attached to two circular shapes of “Fred” and “Ginger” (**figure 6.1-8**). The core occupies the center of the plan creating two zones with rooms, open workstations and conference rooms laid out in radial organization along the naturally lit perimeter. The crescent-shapes circulation areas abut two sides of core and connect to each other through the elevator lobby and a second connection near the party wall.

9

client	Buch und Ton
building name | location	Güttersloh, Germany
shell architects | year	unknown | unknown
layout architects | year	Quickborner Team | 1961
floor area in sq ft - gross | net	27,000 | 24,300
source	(Pile, 1978)

Four external cores are attached to the 205x123 ft floorplate, while two internal ones are positioned 18 ft from the perimeter (**figure 6.1-9**). The pioneering landscaping layout consists of clusters of open-plan workstations that are mostly arranged according to rectilinear grid parallel to the perimeter. However, the circulation among these clusters has an organic configuration with primary circulation linking core to one another and secondary one creating rings around each team cluster.

10

client	Chase Manhattan Bank, Securities Lending
building name | location	Four New York Plaza | New York, NY
shell architects | year	Carson, Lundin & Shaw | 1968
layout architects | year	The Switzer Group | 1998
floor area in sq ft - gross | net	47,400 | 38,800
source	(Slatin, 2001)

The peripheral core occupies the entire length of one side leaving a clear 298x112 ft rectangle for the usable space (**figure 6.1-10**). Columns are spread according to a rectilinear grid of 33x22 ft. Cellular spaces occupy the narrow sides of the plan, while most of the layout is organized with open-plan workstations arranged in clusters of 2x4. The perfect orthogonal grid of circulation is broken at one corner by a large room housing workstations in long rows of 6. A narrow and long strip of conference rooms separates the open plan from the entrance corridor which is located next to the core.

11

client	Chiat/Day Advertising
building name | location	Venice, CA
shell architects | year	Frank O. Gehry & Associates | 1991
layout architects | year	Frank O. Gehry & Associates | 1991
floor area in sq ft - gross | net	22,100 | 18,700
source	(Ragheb, et al., 2001), (Gehry, 1995)

The L-shaped plot has dictated the shape of the floorplate, while the sculptural entrance and the three atria have affected a rather indented perimeter (**figure 6.1-11**). The core, despite small in size, abuts the perimeter and segregates a narrow zone of the floorplate behind it. Pairs of workstations are arranged to form groups of 2x3 and 2x2 in a grid layout. The primary circulation consists of two parallel corridors at the periphery of each wing, whereby two of them connect to form an L-shape spine.

12

client	TBWA Chiat/Day
building name | location	Look Building, 488 Madison Avenue | New York, NY
shell architects | year	Emery Roth & Sons | 1950
layout architects | year	Gaetano Pesce | 1994
floor area in sq ft - gross | net	25,500 | 21,500
source	(Duffy & Powell, 1997)

The compact octagonal floorplate shape is derived by tapering the four corners of a 165 ft square (**figure 6.1-12**). The core is slightly set off the center creating zones of three different depths. The layout pioneered many new concepts of time-sharing and open space club. Most of the area is occupied by meeting spaces that are located at the periphery or further inside creating islands surrounded by circulation. The open-plan workstations are arranged in groups of 2x2 or rows that range in length from five to eleven desks. The circulation has resulted into a conglomerate of meandering segments, straight corridors and radial aisles reinforcing the character of specific zones.

13

client	Citicorp
building name | location	New York, NY
shell architects | year	Skidmore, Owings & Merrill | 1989
layout architects | year	Skidmore, Owings & Merrill | 1989
floor area in sq ft - gross | net	30,200 | 22,800
source	(Skidmore Owings & Merrill, 1995)

The floorplate has a symmetrical shape with 12 corner spaces which are derived by indenting four corners of a 190x190 ft square (**figure 6.1-13**). The large core occupies one quarter of the gross area and is bisected symmetrically by a circulation corridor. The 48 ft deep usable space is organized in two bands: a 24 ft deep area of 3x2 cubicles and a 10 ft deep row of cellular offices along the perimeter. Two racetrack corridors wrap the core and cross with each other to form two rings of circulation. Few meeting spaces are placed among the open plan workstations.

14

client	Commerzbank AG
building name | location	Frankfurt am Main, Germany
shell architects | year	Sir Norman Foster and Partners | 1997
layout architects | year	Sir Norman Foster and Partners | 1997
floor area in sq ft - gross | net	16,850 | 12,300
source	(Myerson & Ross, 1999),

The two sides of the triangle that embrace the garden and the atrium give the usable area the configuration of an L-shape stretched into a 60 degree angle (**figure 6.1-14**). The layout bears resemblances to the “combi-Büro” concept while the circulation between two bands of private rooms widens to allow for teamwork round tables and filing. The ring of circulation is completed by means of the indoors garden connection which links the two corridors at their ends. Such connection is, however, curved, hence reinforcing the role of the garden as a destination rather than a passage.

15

client	Data-Firmengruppe, Grundstückgesellschaft Gniebel GbR
building name | location	Gniebel, Germany
shell architects | year	Kauffmann Theilig & Partner | 1995
layout architects | year	Kauffmann Theilig & Partner | 1995
floor area in sq ft - gross | net	18,600 | 12,900
source	(Myerson & Ross, 1999), (Arnold, Hascher, Jeska, & Klauck, 2002)

The donut shape floorplate is organized around a circular atrium that connects all the six floors of the building (**figure 6.1-15**). The jagged perimeter is surrounded almost entirely by a circular balcony that provides an outer ring of connection among the interior spaces. Three separate cores are located near or around the atrium perimeter. Cellular spaces form a crescent along half of perimeter, while open plan workspaces form a second crescent which is partially sandwiched between the atrium and cellular spaces. The high visibility among workspaces due to transparent partitions is matched by a high permeability due to several doorways between rooms and the connections to the balcony. The layout is a combination of an orthogonal grid, radial connections and a spinning wheel spreading from the circular primary circulation around the atrium.

16

client	Davis Polk & Wardwell
building name | location	450 Lexington Avenue | New York, NY
shell architects | year	Skidmore, Owings and Merrill | 1992
layout architects | year	Gensler | 1993
floor area in sq ft - gross | net	28,300 | 24,500
source	(Iannacci, 1998), (Goldberger & Taylor, 1993)

The rectangular 200x150 ft floorplate has a column-free 52 ft deep usable space developed around a centrally positioned core (**figure 6.1-16**). An unobstructed racetrack circulation is located next to cellular offices of the associates which occupy the entire perimeter. Secretarial open-plan workstation and meeting rooms are arranged into clusters near the core creating a secondary circulation broken into smaller segments. In contrast to the commanding vistas of the primary circulation, the secondary one affords only partial views. The elevator lobby and the waiting area are separated from the main circulation by doors and a staggered configuration thus creating a clear seclusion for guests.

17

client	DEGW
building name | location	London, UK
shell architects | year	unknown | unknown
layout architects | year	DEGW | 1997
floor area in sq ft - gross | net	14,900 | 14,350
source	(Myerson & Ross, 1999), (McGuire, 1998)

The refurbished warehouse consists of three main spaces with width varying from 48 to 52 ft and attached along the length of 96 ft. The primary circulation consists of three corridors that pass through pairs of three doorways across the two party walls. The layout is organized based on the principle of “club” combining individual workspaces with common spaces for team work (**figure 6.1-17**)

18

client	Discovery Channel Latin America / Iberia
building name | location	Miami, FL
shell architects | year	unknown | unknown
layout architects | year	STUDIOS Architecture | 1999
floor area in sq ft - gross | net	44,100 | 21,450
source	(Myerson & Ross, 1999),

Four wings, 80 ft and 75 ft deep, surround the central courtyard (**figure 6.1-18**) where The usable space has an L-shape configuration, since two wings are occupied by machinery and equipment. Three separate cores divide the L-shaped floor into three main zones: a 15 ft-deep area near the outer perimeter laid out with cellular spaces; a 15 ft-deep area near the courtyard perimeter with cellular spaces and meeting rooms; and a 40 ft-deep central area with open-plan workstations in clusters of 5x2. Hence, two primary L-shaped corridors sandwich a series of perpendicular secondary segments between them.

19

client	DuPont
building name | location	Mellon Bank Center | Wilmington, DE
shell architects | year	unknown | 1965
layout architects | year	Quickborner Team | 1967
floor area in sq ft - gross | net	11,850 | 10,200
source	(Pile, 1976), (Pile, 1978)

The floorplate is almost square with sides at 96x104 ft, while the external core occupies three quarters of one side (**figure 6.1-19**). Columns are spread at a rectilinear 28x24 ft grid. The landscaping layout has a band of workspaces at the perimeter and clusters of workstations in the center surrounded by three major rings of primary circulation.

20

client	The Equitable
building name | location	Sperry Rand Bldg., AXA Financial Center, 1290 6th Avenue | New York, NY
shell architects | year	Harrison & Abramovitz and Emery Roth & Sons | 1963
layout architects | year	The Switzer Group | 1997
floor area in sq ft - gross | net	21,900 | 18,500
source	(Slatin, 2001)

The rather typical floorplate is contained inside a 225x100 ft rectangle and has a central core (**figure 6.1-20**). One of the narrow sides is indented creating four corner spaces. The usable space has a 30 ft depth to perimeter. All corner space are occupied by cellular rooms, while open-plan clusters of 6x2 cubicles are arranged with their longest side parallel to the perimeter having circulation paths on both sides. Two primary corridors abutting the longest side of the core run for the entire length of the floorplate and connect most other circulation paths.

21

client	Ford Foundation
building name | location	New York, NY
shell architects | year	Roche / Dinkerloo & Associates | 1967
layout architects | year	Roche / Dinkerloo & Associates | 1967
floor area in sq ft - gross | net	14,400 | 11,900
source	(Duffy & Powell, 1997), (JTB & CRS, 1968)

This building stands in stark contrast to typical US speculative offices: three wings of the Γ-shaped floorplate are naturally lit from both directions due to the narrow depth at 50 ft and 32 ft., while a spectacular atrium provides for cross visibility from one wing to the other (**figure 6.1-21**). The mostly cellular layout is organized in two sides of a primary circulation that runs through the center of wings.

22

client	Ford Motor Co.
building name | location	Cologne, Germany
shell architects | year	unknown | unknown
layout architects | year	Quickborner Team
floor area in sq ft - gross | net	25,550 | 23,350
source	(Pile, 1978)

The floorplate perimeter has a jagged configuration with cantilevered bays 33 ft wide in two sides (**figure 6.1-22**). Columns run according to a staggered configuration, whereas two separate cores abut the two opposite sides of perimeter. Open-plan workstations are clustered in groups and oriented in various directions. The primary circulation of this bürolandschaft layout consists of a major elliptical ring developed between the cores as well as smaller rings among workstation clusters.

23

client	f/X Networks
building name | location	Fox Plaza | Los Angeles, CA
shell architects | year	Johnson, Fain & Pereira | 1987
layout architects | year	Fernau & Hartman | 1995
floor area in sq ft - gross | net	22,650 | 16,550
source	(Myerson & Ross, 1999), (Betsky, 1996a)

The floorplate has a donut configuration surrounding a rectangular 86x71 ft core with a depth from core to perimeter at 40 ft for three sides and 24' 8" for the fourth side (**figure 6.1-23**). Similar to many US skyscrapers built before the financial crisis of late 1980s, the perimeter provides several corner spaces due to 15x15 ft indentations at four corners of the floorplate as well as the protrusions of four double triangles at the middle of each side. The core is penetrated by through-corridors only at one corner, while one of its sides is free from doors and openings. The sixth floor layout stirs away from the conventional racetrack configuration by breaking the primary circulation into smaller tilted segments and doubling some of its parts. Cellular offices occupy the first band of spaces abutting the core, whereas the open-plan "Murphy desks" organized into groups of four are placed on the periphery. The four protrusions at the middle of each side are arranged as thematic meeting spaces coined according to four metaphors relating to the city of Los Angeles.

24

client	Greenberg Traurig
building name | location	Met Life Building | New York, NY
shell architects | year	Emery Roth & Sons, W. Gropius, and P. Belluschi | 1963
layout architects | year	The Switzer Group | 1998
floor area in sq ft - gross | net	35,550 | 25,800
source	(Slatin, 2001)

The massive central core in fourteenth floor of the Met Life has allowed two kinds of spaces in the elongated octagonal floorplate: 37 ft deep and 57 ft deep (**figure 6.1-24**). The layout for this law firm consists of a 15 ft deep band of cellular spaces aligned along the perimeter, a primary octagonal circulation as offset of the perimeter, a second band of open plan secretarial desks, and conference rooms located near the narrow sides of the core. Of the three penetrations through the core, only two connect the opposite sides of the main corridor, while the third is blocked by a kitchenette.

25

client	Hoffmann - La Roche, Inc.
building name | location	Nutley, NJ
shell architects | year	The Hillier Group | 1996
layout architects | year	Gensler | 1996
floor area in sq ft - gross | net	32,850 | 30,000
source	(Iannacci, 1998)

The square-shaped floorplate is broken into four quadrants by two narrow atria and two conference rooms located along four axis of symmetry (**figure 6.1-25**). In contrast to four quadrants that are laid out with cubicles in groups of 2x2 and 3x2, the center of the floorplate creates a clear zone of cellular and conference rooms organized around the core. A ring-like primary circulation circumscribing the central area breaks the grid circulation extending from the cubicles. The elevator lobby at the entrance to the floor gives two directed views across the atria, while the circulation through the open-plan cubicles opens up from one sides of the building to the other.

26

client	IBM
building name | location	IBM Regional Headquarters | Cranford, NJ
shell architects | year	unknown | unknown
layout architects | year	The Switzer Group | 1993
floor area in sq ft - gross | net	88,600 | 86,500
source	(Slatin, 2001)

The large one-story-high industrial shed is laid out according to a strict orthogonal grid that separates well defined functional zones (**figure 6.1-26**). For almost three quarters of the floor, open-plan cubicles are grouped into 5x2, 4x2 and 3x2. Primary circulation corridors have a greater width and are constituted by filing cabinets rather than workspaces. Conference rooms, cafeteria and supporting spaces in the other quarter of the plan interrupt several parts of the rectilinear circulation grid.

27

client	IBM (UK) Limited
building name | location	London, UK
shell architects | year	Michael Hopkins & Partners | 1989
layout architects | year	Michael Hopkins & Partners | 1989
floor area in sq ft - gross | net	41,600 | 35,000
source	(Duffy & Powell, 1997)

This Bedfont Lakes three-story high building is organized around a rectangular central atrium bisected by a catwalk connecting two sides of the floorplate to the elevator and stairs (**figure 6.1-27**). In a perfect symmetry, there are four larger cores located along the 62 ft deep plan surrounding the atrium, and four smaller ones located in pairs between the former. As one of the earliest examples of club configuration, the orthogonal layout is sandwiched between two racetrack primary circulation paths: the inner one abutting the atrium and the outer one 16 ft deep from the perimeter. Cellular spaces and groups of 2x2 open workspaces are located along both outer and inner perimeters, while the central part of the floor is occupied by filing and conference rooms.

28

client	IBM Australia
building name | location	IBM Australia Centre, Southgate | Melbourne, Australia
shell architects | year	Buchan, Laird & Bawden | 1993
layout architects | year	Daryl Jackson International | 1994
floor area in sq ft - gross | net	15,100 | 12,300
source	(Myerson & Ross, 1999), (Styant-Browne, 1995)

The elongated hexagon floorplate with a central rectangular core favors the extension of three axes: two parallel to the long side of the core and the third one penetrating the core (**figure 6.1-28**). This geometry creates four distinct convex regions in the floor. The 28th level contains mostly meeting rooms which have been arranged around two corridors parallel to the long sides of the plan. Several rooms allow for through movement and create a ring-like structure of connections which is, however, staggered and deflected away from the linear organization.

29

client	Interpolis
building name | location	Tilburg, The Netherlands
shell architects | year	Abe Bonnema | 1997
layout architects | year	Abe Bonnema, Kho Liang Ie Associates | 1997
floor area in sq ft - gross | net	6,750 | 4,850
source	(Myerson & Ross, 1999)

The main wing is accessed from the detached core through a glass bridge at the end of the floor. Bonemma's design represents a perfect example of a tight fit between the narrow 39 ft floorplate and the simple layout organized with cellular rooms on two sides and open-plan team work area along the central axis (**figure 6.1-29**). One of the two primary circulation routes that surround the central block of workstations extends through the entire length of the floorplate. The second circulation is broken by the block of the conference rooms and copy room which protrudes further inside than the individual offices, hence reinforcing the detachment of the deeper end of the office. The sense of depth given by the elongated floor is contradicted by a high degree of openness and transparency in all directions as well as through the glazed partitions of cellular spaces.

30

client	Direct. of Telecom, Ministry of Public Buildings and Works, UK
building name | location	Kew, UK
shell architects | year	Whitehall Project Group | 1968
layout architects | year	Whitehall Project Group | 1968
floor area in sq ft - gross | net	15,100 | 14,400
source	(Pile, 1978), (Whitehall, 1969)

The floorplate of the second floor is a square with a 123 ft side (**figure 6.1-30**). The core is located off center 20 ft deep from the perimeter. The layout is a fully fledged bürolandschaft where hexagonal desks have allowed many configurations of clustering workstation. The primary circulation has a sinuous shape and extends from one side of the floor to the other wrapping two sides of the core.

31

client	Eastman Kodak
building name | location	Rochester, NY
shell architects | year	unknown | unknown
layout architects | year	Quickborner Team | 1967
floor area in sq ft - gross | net	33,500 | 28,300
source	(Pile, 1976), (Pile, 1978)

The floorplate of this portion of the Kodak Rochester Complex is a 275x130 ft rectangle where cores indent three sides at depths of 36 ft, 22 ft and 20 ft (**figure 6.1-31**). A dense grid of columns is spaced at 20’x18’6” bays. The primary circulation of this bürolandschaft layout can be best described as series of sinuous paths connected in a tree-like structure. Most team clusters have desks arranged according to rectilinear grids.

32

client	Lend Lease Interiors Pty Ltd.
building name | location	Australia Square Tower | Sydney, Australia
shell architects | year	Harry Seidler, Pier Luigi Nervi | 1967
layout architects | year	Bligh Voller, DEGW | 1995
floor area in sq ft - gross | net	10,700 | 8,450
source	(Duffy & Powell, 1997)

The usable space has a donut-shape of 39'6" and 9'6" radii (**figure 6.1-32**). Three main corridors pass tangent to the core and terminate and connect to each other at the location of three meeting spaces. The "den" layout, placed perpendicular to each corridor, contains open-pan workstations grouped into bays with filing cabinets and meeting desks in the middle.

33

client	Leo A Daly
building name | location	Proscenium | Atlanta, GA
shell architects | year	Thompson, Ventulett, Stainback & Associates | 2001
layout architects | year	Thompson, Ventulett, Stainback & Associates | 2001
floor area in sq ft - gross | net	24,450 | 21,050
source	TVS & Associates

The floorplate shape is derived by indenting the narrow side of a 240x119 ft rectangle thus creating five corner spaces (**figure 6.1-33**). The core is centrally located 43 ft deep from the perimeter. Two main corridors are slanted towards the meeting rooms creating a trapezoid configuration. The secondary circulation forks into a Y shape between staggered open-plan workstations, which form clusters of three and five.

34

client	Lowe and Partners/SMS
building name | location	W.R. Grace Building | New York, NY
shell architects | year	Skidmore Owings & Merrill | 1973
layout architects | year	Sedley Place | 1998
floor area in sq ft - gross | net	26,800 | 20,900
source	(Myerson & Ross, 1999), (Krinsky, 1988)

The floorplate is a typical 225x120 ft rectangle with a large central core and a 35 ft deep usable space (**figure 6.1-34**). The entire perimeter is occupied by cellular spaces which are of two depths. These two kinds of rooms are clustered in groups, hence creating pocket spaces near doorways. Several filing cabinets are interspersed along the rather wide corridor at 12 ft giving a sense of meandering circulation.

35

client	McDonald’s
building name | location	Helsinki, Finland
shell architects | year	Heikkinen-Komonen Architects | 1997
layout architects | year	Heikkinen-Komonen Architects | 1997
floor area in sq ft - gross | net	17,700 | 15,450
source	(Myerson & Ross, 1999), (MacKeith, 1999)

The shape of the hamburger seems to have inspired the cylindrical volume of the six-story building of the McDonald’s Finnish headquarters (**figure 6.1-35**). The structural grid of the circle-shaped floorplate is, however, organized along four quadrants of 48’ 10” bays. The rectangular shaped core is positioned off the center of the circle aligned to a perfectly square-shaped primary circulation. Open plan workspaces are located on three sides of the primary circulation, while meeting spaces, conference rooms and filing are located in the fourth side as well as in the center. The secondary circulation on the outer side of the primary corridor does not always align with the open paths between filing cabinets in its inner side resulting in an overall circulation with a staggered and broken orthogonal grid.

36

client	McDonald’s Italia Company
building name | location	Milan, Italy
shell architects | year	Atelier Mendini | 1997
layout architects | year	Atelier Mendini | 1997
floor area in sq ft - gross | net	26,750 | 21,500
source	(Myerson & Ross, 1999)

The unobstructed area, where five separate cores are located at the periphery of the 240x87 ft floorplate, allows for a multitude of layout fits (**figure 6.1-36**). Interestingly, the unusual design by Mendini defies an organization that reinforces the floorplate linearity by dividing the layout into two zones through a sinuous spine of cellular spaces. The passage through the curved spine is oriented towards the shortest axis of the floor, while the open-plan 2x2 workstations are scattered into staggered locations reminiscent of bürolandschaft principles. Two of the meeting rooms in the dividing spine have doors in both sides, hence enhancing choices of movement in the office.

37

client	MGIC
building name | location	Milwaukee, WI
shell architects | year	Skidmore, Owings & Merrill | 1972
layout architects | year	Warren Platner Associates | 1972
floor area in sq ft - gross | net	22,500 | 20,150
source	(Pile, 1976)

The 150x150 ft plate of the fourth floor of the headquarters building is organized on a structural grid of columns on 30 ft spacing, and a cantilevered 15 ft strip on the periphery (**figure 6.1-37**). The elongated 75x30 ft core has a central location in the plan. The layout is predominantly composed of cellular offices located at the perimeter as well as conference rooms. Few open-plan workspaces are arranged in groups of 2x3, 2x 2, and 4x1. In addition to a central ring of circulation abutting the core, a U-shaped circulation surrounds three sides of the plan 15 ft deep from the perimeter. The fourth side of the plan is designed with two rows of partitioned conference rooms and open meeting rooms. All permanents partitions reaching high to the ceiling result in series of rectilinear separated spaces located along main circulation paths.

38

client	Nickelodeon
building name | location	One Astor Plaza | New York, NY
shell architects | year	Kahn & Jacobs, Der Scutt | 1972
layout architects | year	Fernau & Hartman, Kohn Pedersen Fox | 1995
floor area in sq ft - gross | net	29,800 | 24,300
source	(Duffy & Powell, 1997)

The floorplate shape is derived by attaching four small wings at spiral symmetry to a 165 ft square (**figure 6.1-38**). In addition to four fire staircases located near each extrusion, the core occupies the inner portion of three quadrants of the floor allowing for a cross-shaped corridor passing through it and a free 36 ft band of open space at the periphery. While such cross is utilized to become an important part of the circulation, the outer ring is broken for most of its length due to wrapping the islands of support rooms placed at odd angles. The circulation, hence, results in a combination of few long orthogonal elements attached to several shorter elements intersecting at wide angles.

39

client	Olivetti
building name | location	Bari, Italy
shell architects | year	DEGW, Studio De Luchi | 1990
layout architects | year	DEGW, Studio De Luchi | 1990
floor area in sq ft - gross | net	5,650 | 5,650
source	(Duffy et al., 1998), (Vidari, 1990)

Olivetti headquarters consist of two symmetrical wings mirrored along the courtyard (**figure 6.1-39**). Each wing is composed of three pavilions separated by a zone of cores and connected through two main corridors that run unobstructed along the entire length of the wing from one external core to the other. The two corridors divide the width of the pavilion in three bands of usable space two at the periphery of each pavilion and one at the center. Here, I have analyzed the floorplate portion which is identical for all pavilions and the different layout configurations found in three pavilions. In pavilion A, each of the two outer bands are arranged with three separate rooms where groups of two workspaces are located at each side of the room leaving a free aisle in the middle. The inner band is occupied almost entirely by a larger room with three rows of desks which also provides connections from one of corridors to the other.

40

(ibid. olivetti-a)

The layout of pavilion B is mostly open-plan (**figure 6.1-40**). At the inner band, workstations are oriented to allow cross circulation paths from one main corridor to the other. In contrast, the outer bands are organized along a secondary circulation that runs parallel to the main corridors where groups of two workstations are located at each side staggered between them giving the aisle a meandering effect.

41

(ibid. olivetti-a)

In the predominantly open-plan pavilion C group of 2x2 workstations are arranged staggered in both width and length (**figure 6.1-41**). While meandering aisles run in all directions, those at 45 degree to the main circulation get a prominent role in connecting the two main corridors as well as secondary circulation near the periphery.

42

client	Orenstein-Koppel
building name | location	Dortmund-Dorstfeld, Germany
shell architects | year	unknown | unknown
layout architects | year	Quickborner Team | 1963
floor area in sq ft - gross | net	18,850 | 17,500
source	(Pile, 1978)

Two cores and a small atrium are located off center and 22 ft deep from the perimeter of the 174x110 ft floorplate (**figure 6.1-42**). In contrast to the organic layout of the first floor, the second floor in consideration contains workstations grouped into rather long clusters of up to eleven desks according to an orthogonal orientation. However, due to the staggering of clusters, the circulation displays a pattern all too familiar for the bürolandschaft: curvilinear paths that branch form each other and form rings.

43

client	Sears
building name | location	Sears Tower | Chicago, IL
shell architects | year	Skidmore, Owings & Merrill | 1974
layout architects | year	SLS/Environetics Inc. | 1974
floor area in sq ft - gross | net	52,000 | 44,100
source	(Pile, 1976)

Four rows of columns, which are spaced at 15 ft, cross the square-shaped floorplate in two orthogonal directions forming nine column-free 75x75 ft regions (**figure 6.1-43**). The large core occupies most of the central region as well as parts of the adjacent regions according to a cross configuration, leaving the remaining four corner regions of the floorplate completely for usable area. Three corridors abutting the rows of columns and a fourth one passing through the center of the floorplate divide the core into seven parts. Almost half of the perimeter is occupied by 10x15 ft cellular offices, whereas the rest of the layout is composed of separated open-plan workspaces organized in an orthogonal grid. In addition to primary circulation paths that extend those created by the core, a racetrack circulation, positioned 15 ft deep from perimeter, circumscribes the entire layout.

44

client	unknown
building name | location	Sears Tower | Chicago, IL
shell architects | year	Skidmore, Owings & Merrill | 1974
layout architects | year	The Environments Group | unknown
floor area in sq ft - gross | net	29,500 | 23,100
source	(Mays, 1999)

As four corner regions stop at lower height, the floorplate above the seventieth floor is composed of five regions that form a cross configuration (**figure 6.1-44**). Three of the regions contain the elongated core; the fourth one has been carved in its center by a large support room; while the fifth one is entirely usable space. The whole perimeter is occupied by cellular spaces, whereas the kernel of the fifth region has a ring-like circulation wrapping a group of open-plan secretarial workstations. Two primary corridors in both sides of the core dominate the layout.

45

client	Steelcase Inc.
building name | location	Steelcase Corporate Headquarters | Grand Rapids, MI
shell architects | year	WBDC, Inc. | 1983
layout architects | year	Steelcase, F. Steele | 1995
floor area in sq ft - gross | net	24,100 | 20,200
source	(Duffy & Powell, 1997)

There are two external cores serving the 147x140 portion of floorplate of the “Leadership Community” (**figure 6.1-45**). A primary circulation is composed of a racetrack primary circulation offset 14 ft from three sides of the perimeter and two central corridors that connect from one core to the other. The central part of the floor, located between the two primary paths and the two cores forms a spine of conference rooms and informal meeting area. Den open-plan workstations are located on both sides of the spine clustered into teams. While the secondary circulation is orthogonal, it does not align from one team space to another hence creating a broken grid.

46

client	British Telecom
building name | location	5 The Longwalk, Stockley Park | London, UK
shell architects | year	Sir Norman Foster & Partners | 1989
layout architects | year	Sir Norman Foster & Partners and DEGW | 1996
floor area in sq ft - gross | net	66,000 | 54,400
source	(Duffy & Powell, 1997), (Duffy et al., 1998)

The floorplate consist of three pavilions that were designed to allow for flexibility of change between one to three tenant occupations (**figure 6.1-46**). Four bridges, aligned into two major circulation paths, connect the pavilions spanning across the narrow atria. Seven cores are scattered on the end of each pavilion as well as along their central zones. The DEGW refurbishment, carried out after BT acquired the building from BP, is mainly open-plan of 2x2 and 2x3 workstations organized in a pure orthogonal grid derived by intersecting two bridges with pairs of circulation paths for each pavilion.

47

client	British Telecom
building name | location	The Square, Stockley Park | London, UK
shell architects | year	Arup Associates | 1996
layout architects | year	Arup Associates and DEGW | 1996
floor area in sq ft - gross | net	18,200 | 16,450
source	(Duffy et al., 1998), (Greenberg, 1997)

The floorplate shape is developed by joining the triangular edges of a cruciform which is composed of nine 52’6” squares (**figure 6.1-47**). The resulting floor corners at 90 and 135 degrees have produced two competing axis oriented at 45 degrees to each other. The layout is arranged by aligning open-plan workstations, of 2x1 and 2x2 clusters, to the perimeter, while filing cabinets and conference rooms are aligned with the direction implied by the central core and the two peripheral staircases. The circulation can be described as two orthogonal grids colliding at 45 degrees and being interrupted by each other.

48

client	Vitra International AG
building name | location	Basel, Switzerland
shell architects | year	Frank O. Gehry & Associates | 1996
layout architects | year	Frank O. Gehry & Associates | 1996
floor area in sq ft - gross | net	12,250 | 10,100
source	(Duffy & Powell, 1997)

Similar to his earlier Chiat/Day California, Gehry juxtaposes the sculptural “villa” entrance block to a conventional office wing (**figure 6.1-48**). This wing has a broken shape where a square is added to the 156x38 rectangle. Two narrow bridges fan out from the entrance block and connect it with the office wing at 1/3 and 2/3 of its length. The primary circulation joins the spine of the office with two bridges and two external cores, hence a configuration of a ring attached to a linear element. The layout is a combination of cellular spaces, semi-open plan and open-plan arranged in both sides of the main circulation spine.

49

client	Weyerhaeuser Company
building name | location	Tacoma, WA
shell architects | year	Skidmore, Owings & Merrill | 1974
layout architects | year	Sidney Rodgers Associates | 1974
floor area in sq ft - gross | net	45,950 | 41,750
source	(Pile, 1976), (Canty, 1977)

The floorplate portion in consideration is a 438x195 ft rectangle (**figure 6.1-49**). Two cores are located near two opposite angles, each composed of three blocks that imply a cross circulation between them. Four doorways at four corners connect the wing to other parts of the Weyerhaeuser complex. A staggered grid of columns is developed in two axes: the first is parallel to the shortest side of the floor with spacing at 15 ft; the second is at 30 degree angle to the longest side and spans at 20 ft. The open-plan layout is one the largest project in the US to use the landscape concept. Desks are clustered according to teams, whereby groups are separated by wider circulation corridors. While all the furniture are oriented in a rectilinear grid parallel to the shortest depth of the floor, their staggered location to each other has created several circulation paths in various orientations. Hence, the circulation structure is in clear contrast to the geometrical order implied by the floorplate shape and the dense grid of columns.

50

client	WMA Consulting Engineers
building name | location	Chicago, IL
shell architects | year	
layout architects | year	Valerio Dewalt Train Associates | 1996
floor area in sq ft - gross | net	23,000 | 17,300
source	(Myerson & Ross, 1999), (Russell, 1997)

This loft renovation is constrained by a deep 100x200 ft rectangular floorplate with a dense grid of columns at 20x24 ft (**figure 6.1-50**). The elongated core occupies the entirety of one of the long sides narrowing further the usable area. The layout design has sought to minimize hierarchy and status and promote interaction in this engineering firm. An orthogonal grid open plan of 8x10 ft U-shaped desks occupies the center of the plan while two tiers of cellular offices on both sides align to the open plan grid allowing the connection of shorter circulation segments with two main corridors located in the periphery. The simplicity of the layout arrangement contrasts with a dynamic lighting system oriented along diagonals in the ceiling as well as in staggered levels on the walls.

Appendix 2 Second Part of Duffy's Model: Description and Classification of Layouts

This section reviews models that investigate office layouts linked to organizational aspects. Duffy proposes two physical descriptors of layouts: *differentiation* and *subdivision* in order to capture major variations between layouts:

> "The first physical variation can be called *differentiation*, the degree to which all the workspaces in a given layout are distinguished from one another by physical means, such as the number of square feet allotted to each or the number of pieces of furniture in each… The second kind of physical variation is *subdivision*, that is the degree to which all the workspaces in a given layout are cut off from one another by screens and partitions" (Duffy, 1974: 219)

The two variables are independent from each other and they can be combined in a model with two axes dimensioning the degrees of the variables from low to high resulting in four permutations of layouts: *the research establishment, clerical office, corporate headquarters,* and *design office* (**figure A2.1**).

The structure of organizations is considered crucial to explain physical differences observed in layout cases. As to the sociological dimension of the model, Duffy recognizes two key concepts that are basic for describing organizations: *bureaucracy* and *interaction*.

> "Bureaucracy is a convenient label for one group of concepts… (including) division of labor, hierarchy of authority, extensive rules, separation of administration from ownership, and hiring and promotion based on technical competence… Interaction is another central group of concepts (including) the number of contacts in organization, their frequency, importance, and confidentiality." (Duffy, 1974: 221)

The two layers of the model consider *bureaucracy* to explain the *differentiation*, and the *interaction* to explain degrees of *subdivision*. The model is based on two hypotheses: first, organizations that are highly bureaucratic are likely to be housed in office layouts with workplaces differentiated from one another; second, organizations that are highly interactive are unlikely to be accommodated in layouts with a great deal of physical subdivision, hence the two layers of the model can be overlaid to describe correspondences between pairs of layout descriptors and pairs of organization descriptors (**figure A2.1**).

The correlations between physical variables (area of workplace, expense – the quality of furnishing of each workplace, the number of activities supported by each workplace, equipment – the number of pieces of furniture in each workplace, enclosure – as a score of the four sides of the workplace, and accessibility – the ease of approach between any workplace and the four nearest workplaces) and organizational variables measured by questionnaires (rank job, assessment of the degree of bureaucracy, and the quantity and quality of contacts) do not fully support the hypothetical model. While, as expected, organizations with high interaction are found to use less subdivided layouts, non-bureaucratic organizations are found to use high differentiated layouts on the contrary of the prediction. Another unexpected result is that the variables of bureaucracy and interaction are found to relate to each other. The bureaucratic variables are found to correlate with physical ones in the individual level and not in the aggregate level of the entire organization. According to Duffy, these results are explained by the effect of *standing* or status in organization, “status in an organization is more likely to be based on authority and professional training than on the nature of work” (ibid.: 232).

Interaction is found to be independent from degrees of subdivision and differentiation of layouts, but occurs more in organizations composed of people of low standing, while organizations composed of people of high standing tend to aggregate subdivision. In conclusion, Duffy finds that standing and interaction are two independent variables, and that the symbolic properties of layouts, reflecting the individual standing, are more critical than the operational ones.

Building upon the distinction between shell and scenery, discussed earlier, Duffy and Cave (1976) enhance the earlier model towards proposing typological fits between organizational styles and kinds of scenery. Four major kinds of sceneries, i.e. layouts, are suggested: *cellular* consisting of rooms of up to five people; *group spaces*, which are medium size space for five to fifteen people; *open-plan* which is characterized by the absence of sub-division and rigid arrangement of workspaces; and *bürolandschaft* as described earlier. Organizations are described as requiring different degrees of interaction, supervision and confidentiality and are classified based on the four types proposed by Duffy (1974). Each organization is represented with graphs that depicted the required management task links between groups and individuals as well as clustering of related individuals (**figure A2.2**) The matrix of fit between organizational variables and physical characteristics of layouts shows qualitatively how each layout type is potentially able to fulfill the organizational requirements. In his later work, Duffy enhances the model to incorporate new managerial trends and IT developments in the office layouts (Duffy and Powell 1997). Organizations are characterized by four kinds of work patterns that combined different levels of *autonomy* and *interaction*: *hive, cell, den*, and *club* (**figure A2.3**). A case-by-case analysis illustrates how certain office settings represent best the proposed organization types. The focus shifts from the shell as constraining or generating into a scenario more liberated from shell constraints where the IT and other technical improvements in services take the lead in affecting setting solutions. Properties of the shell in generic sense are not considered as much as components of the translation between managerial ideas and work patterns into physical arrangements. On the contrary, apart from discussing at length the settings suitable for dens, clubs, cells and hives, the study describes specific tailored examples where the architecture has succeeded in matching and creating the organization image.

Similar to the fitting of sceneries into floorplates, which was discussed in the Chapter 2, the model by Duffy and Cave for matching organizations with layout types evaluates conditions of workplaces or groups of workplaces in the local scale. Accordingly, the fulfillment of organizational requirements is achieved when the needs of individual workplaces are provided. The thesis argues that not all the organizational requirements have an aggregative nature and it is not always possible to break them down into elemental requirements of local workplaces or regions. For instance, it is not possible to designate specific workspace conditions to achieve the goal of an organization like British Airways for increased synergy (Grajewski, Hillier et al. 1994). As a result, the limitation of founding the fit between organizations and sceneries as well as the fit between sceneries and shells on aggregated local correspondences is transmitted into the proposed planning and design procedure of composing the stacking plan (Duffy 1974).

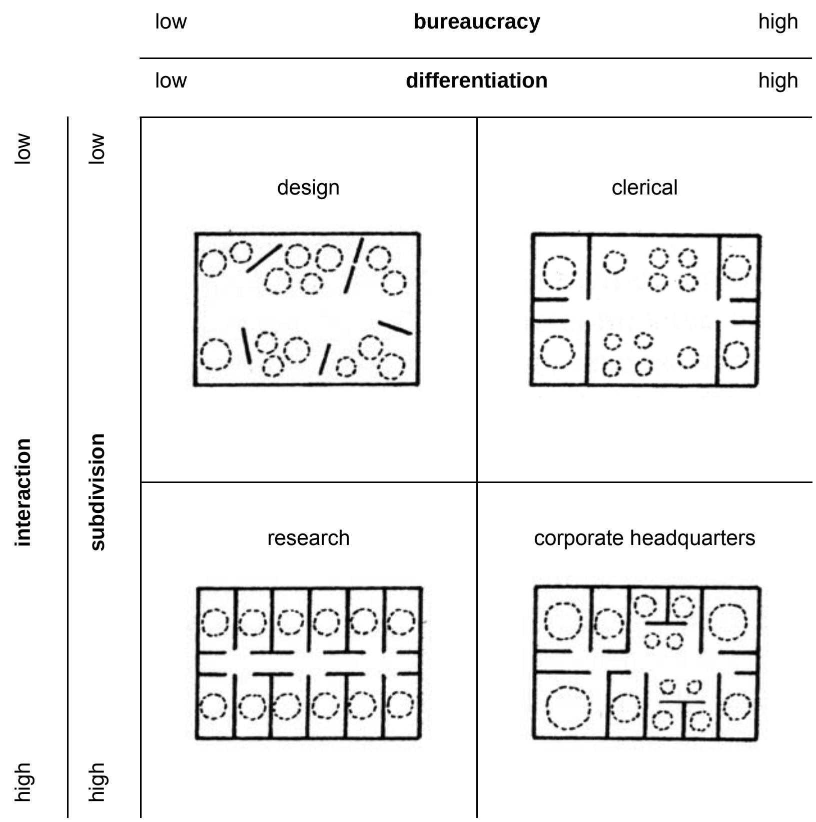
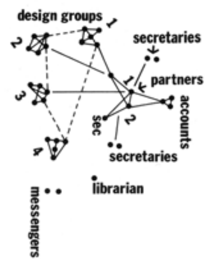


Figure A2.1: The hypothetical model of relating layout variables of differentiation and subdivision with the organizational dimensions of interaction and bureaucracy. Four kinds of organizations are positioned accordingly.

<table>
<tr><td></td><td></td><td>design office

Intensely interactive project-based groups in loose touch with each other. Serviced by normal support functions. Visitors at all levels. Partners in close touch. Concentrated work with occasional confidentiality.


</td><td>advertising agency

Isolated work groups, coordinative work. Two kinds of groups; working group competes for the services of the other. Usual support services. Directors not involved in day-to-day work; concerned with clients.

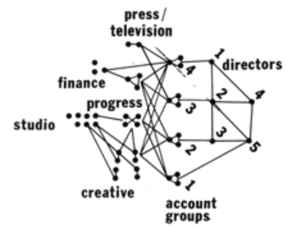
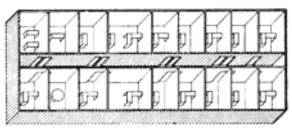
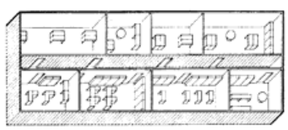
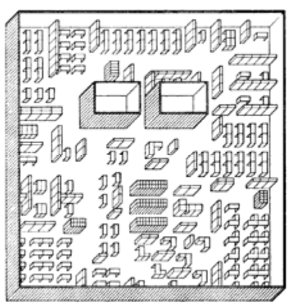
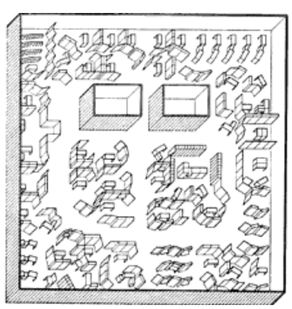

</td></tr>
<tr><td>cellular</td><td></td><td>Unsuitable because of group size and informal interaction. Separate rooms breed isolation.</td><td>Unsuitable because of group sizes though could be made to work.</td></tr>
<tr><td>group space</td><td></td><td>More suitable than cellular, though still not ideal</td><td>Most suitable. Groups prefer this degree of territorial definition.</td></tr>
<tr><td>open plan</td><td></td><td>Inappropriate for method of working, management style and occasional need for privacy (meetings).</td><td>Inappropriate for method of working and management style.</td></tr>
<tr><td>landscaped</td><td></td><td>Probably very suitable. Group identity and territorial definition sustained – with day-to-day rearrangement potential. Allows easy access for visitors.</td><td>Not very suitable. Frenetic and competitive mode of working disturbs others.</td></tr>
</table>

Figure A2.2: Degrees of fit between requirements of four types of organizations and features of four types of office scenery.

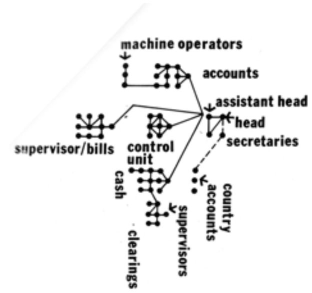
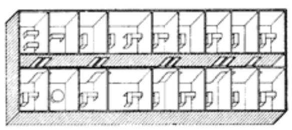
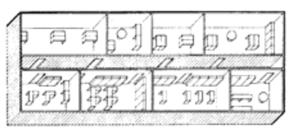
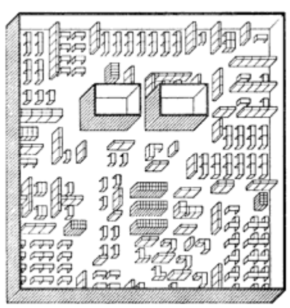
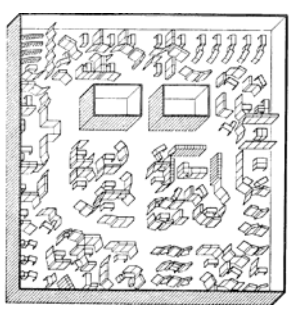
		top management	clerical office
		Isolated executives with secretarial and PA support. Confidentiality and contemplative work. Visitors. 	Large supervised groups – paper and/ or machine intensive. Highly intra-active groups. No public entry. 
cellular		Suitable; permits confidentiality and suitable reception of visitors. Special arrangements required for board room.	Unsuitable for large groups – isolation incompatible with supervision requirements
group space		Possibly suitable but spaces may be too large.	Possibly suitable – depends on space and group size, though similar problems as cellular.
open plan		Unsuitable, incompatible with status management style and requirement for confidentiality.	Suitable, accepts group size fluctuations, supervision and high interaction.
landscaped		Unsuitable. Top management too exposed.	(Suitable) As open-plan but supervision restricted.

Figure A2.2 continued.

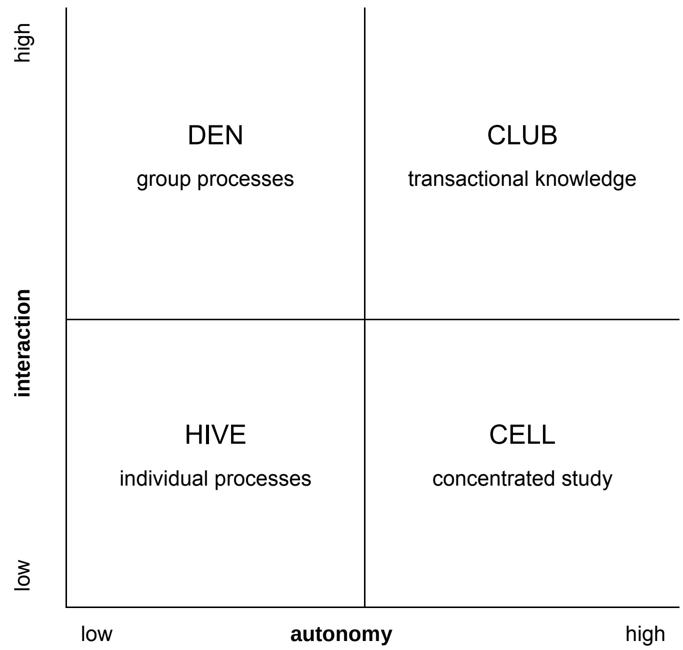


Figure A2.3: Four major organizational types as degrees of autonomy and interaction. They are a shorthand way for describing affinities between work patterns, the use of space, and the demands likely to be made by these groups on environmental services.

Appendix 3 Enhancing Hillier's Model to Deal with Non-Convex Circulation

In the chapter "Is Architecture an Ars Combinatoria?" Hillier (1996) analyzes the effect of adding partitions on the distribution of depth in a permeability complex, which is arranged by elementary units according to a rectangular uniform grid. Each cell has been assigned a value of *depth count* as the sum of grid distances to all other cells. The *total depth* of the complex is calculated by summing up *depth counts* of all cells in the complex. The local-to-global effects of adding partitions or openings in a permeability complex have been considered as design principles from which we can forecast the global effects with regard to changes in values of *total depth*. Four such principles have been summarized.

> "...the principle of centrality: more centrally placed bars create more depth gain than peripherally placed bars; the principle of extension: the more extended the system by which we define centrality (i.e. the length of lines orthogonal to the bar) then the greater the depth gain from the bar; the principle of contiguity: contiguous bars create more depth gain than non-contiguous bars or blocks; and the principle of linearity: linearly arranged contiguous bars create more depth gain than coiled bars" (Hillier, 1996: 299).

Of particular interest to this discussion is the reverse experiment, where openings or large spaces are introduced instead of partitions. Their effect is to reduce depth rather than increase it. It has been shown that the same principles are valid, if *depth loss* is substituted with *depth gain*. Therefore, more depth loss results from: central openings rather than peripheral ones; the longer the openings; openings that are contiguous rather than positioned apart; openings that are placed in a linear rather than coiled. The depth minimizing moves, applied consistently over a floorplate, leads to the creation of long linear corridors, while the depth maximizing ones leads to broken corridors and irregular patterns of subdivision. The emergence of corridor-like connections among cells minimizes the total depth in a system, and is influenced by the three principles of *extension*, *contiguity*, and *linearity*. According to the principle of *centrality*, corridors that are positioned centrally in a floorplate minimize depth more than peripheral ones.

With regard to representing and measuring features of complexes that comprise open spaces, Hillier's model has certain built-in limitations that result from the issue of maintaining convexity. In that model, original cells are merged into open spaces which are kept always convex (**figure A3.1**). If we were to think of these spaces as joined to create circulation spaces, they would quite possibly form non-convex entities (**figure A3.2a**). For the purpose of analyzing a system that includes non-convex circulation spaces, the circulation system needs to broken up into convex components. At this point the idea of fixed and discrete convex partitions of circulation spaces does not appear fully satisfactory. This is due to the fact that alternative partitions of the same circulation system into convex segments may best represent how well this system serves to make connections between adjoining areas of the complex. In a symmetrical L-shaped circulation space, each of two alternative partitions into two convex spaces may make the distance between some adjoining cells appear deeper. In (**figures A3.2b** and **A3.2c**), the same circulation system is divided into convex entities in two different ways, hence resulting in different total depth values of 2912 and 2892. Hillier's argument has been developed on a model which consists of a series of segmented and scattered open spaces, in which the issue of dividing a continuous and non-convex open space into convex entities is not addressed.

The difficulty of the Hillier's model consists on the fact that a single type of cell has been used to deal with both unitized regions and with open ones in the complex. After the mechanical merging of cells into larger entities, the emerged unit maintains the same features of the original ones, i.e. permeability connection to the adjacent ones. Here, an alternative strategy is proposed. The underlying units of space that are part of circulation are not allowed to merge into a single pattern of larger convex spaces; instead, their identity is preserved. Consequentially, finding plausible convex break ups of the circulation system is thus replaced by a new approach of dynamic depth calculation, which is always unique and unambiguous for a given location. This model is described in section 5.2 of Chapter Five.

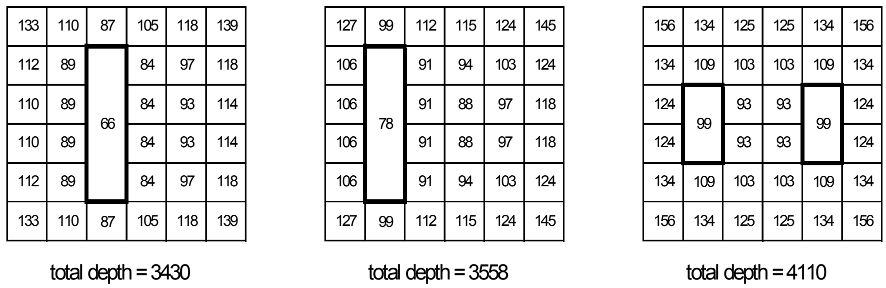


Figure A3.1: Introducing open spaces of corridors or courts, shown with bold contour, by merging units of an adjacency complex. The principles of centrality and extension are illustrated with openings which are convex and detached from each other.

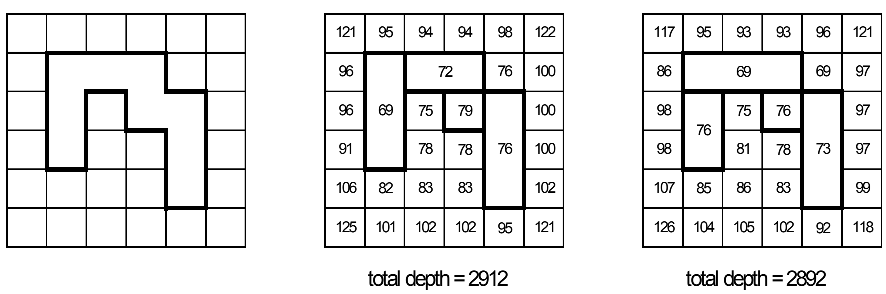


Figure A3.2: The controversy of introducing non-convex openings according to Hillier's model. Two ambiguous convex break-ups of the opening result in different total depths of the complex.

Appendix 4 Hot Spots and Principles of Fitting Circulation Systems into Floorplates

The system of circulation spaces is crucial for structuring the entire layout; its structure determines by and large the structure of the layout. In the case of a good match between layouts and floorplates, for layouts to take full potential of the capabilities of floorplate shapes, the arrangement of the circulation needs to be guided by specifics of the floorplate. This section seeks to discover the underlying structure of shapes which guides the composition of the circulation system.

Throughout the following experiments, the criterion of having the highest possible integration has been adopted as a guiding principle. While, integrated circulation structures are preferred to segregated ones, it is aimed to find the best ways of embedding them into the shape so as to achieve the highest integration. An obvious start is to include as many areas of low depth as possible as part of the circulation system while aiming at producing the maximum loss of depth through the placement of circulation.

Hot spots, detected from the analysis of shapes with c-units, provide the clue for solving the problem. Hot spots emerge at the intersections of wings, or linear parts of the shape. They have a distinct significance in terms of capturing positions from where a considerable portion of the shape is in linear access. The lower the value of a certain area, the larger the proportion of the shape is in convex access from it. Areas that have a depth equal to zero have convex access to the entire shape. Hot spots capture primarily the extension of linearity and convexity in the shape given the concept of convex fragmentation in which their calculation is based. Thus, intuitively, we can think of them as the pivotal points through which the circulation systems must pass if the condition of providing highest integration of the overall complex is imposed.

A number of experiments of fitting circulation systems in several shapes are carried out by changing the status of tile units in a floorplate from o-units into c-units. Hence, carving out openings in the shape, originally composed entirely with o-units, creates mixed complexes of o-units and c-units, the first representing occupation regions and the second representing circulation spaces. Except for the convex fragmentation, c-units share the same qualities with o-units. The depth between two adjacent units increases each time by one when: 1- a threshold is crossed between an o-unit and c-unit; 2- c-unit and o-unit; 3- two o-units; 4- two c-units when convexity is broken. After each transformation, combined depths are calculated for each unit, and aggregates are summed up for the entire shape. When the shape is mapped entirely with o-units, the maximal depth for a unit is achieved. To gauge the effect of converting o-units into c-units with regard to minimization of depth or enhancement of integration in a complex, I introduce the measure of Loss as the difference between GD and combined depths in the combined complex of o-units and c-units.

$$Loss = gd - \left(\sum_{i=1,\, j=1}^{i=n+m,\, j=n+m} (gd_{ij} + ocd_{ij}) \right) \qquad \text{(A4.1)}$$

where gd_{ij} is the grid distance between two o-units i and j,

ocdij is the convex overlap depth between c-units i and j

n is the total number of o-units in the shape

m is the total number of c-units in the shape.

Finding the most integrated solution is equivalent to finding the highest value of Loss. When two trials are compared, the change resulting from the one with greater Loss value is chosen, reversing all the moves that have given a lower Loss. The shape is analyzed in two ways: represented entirely with o-units (**figure A4.1a**), and entirely with c-units (**figure A4.1b**). For each location in the complex emerging from converting o-units into c-units, references are made to their respective condition in the two original states.

In the shape represented entirely with o-units, the location coinciding with the hot spot with the lowest ocd at 51, marked with A, is converted into c-unit (**figure A4.1c**). Due to the principle of contiguity, the next o-unit to be converted has to be adjacent to A. The conversion of A1 gives a higher Loss at 723 than A2 with a Loss at 704, so the first choice is kept. The next step involves trying the units adjacent to A1. The conversion of A11 would be a better solution than A12, as it is reinforced from the result of analysis where the Loss for A11 at 1479 is higher than the one of A12 at 789, hence confirming the principle of linearity.

A linear corridor in the bottom of the shape thus emerges. Other conversions extend this elementary corridor further until it connects to the other position coinciding with the hot spot B with ocd of 51. Because of the linearity associated with the convex fragmentation, the first line of circulation not only connects the first hot spots according to the rank of integration, but it also covers all other hot spots with depth values next to the lowest. Therefore, connecting first hot spots guarantees the best choice to obtain the highest integration for the number of converted units. Due to the apparent central position, it may seem obvious that the next move would be connecting C with D, as shown in (**figure A4.1d**), which gives a Loss at 6392. On the contrary, connecting A to the next lowest hot spot E with ocd of 76 (**figure A4.1e**), is the best option with a Loss higher than C-D at 7460. This holds true for all next moves. The first principle of fitting circulation systems into a shape is defined as follows:

> P1 Connecting positions that coincide to hot spots, as detected from analysis with c-units, in a hierarchical order starting from the hot spots with the lowest depth, guarantees the most integrated solution for the same number of converted units.

For cases where there are more than two equal values of hot spots in the rank, it becomes an issue which one of them to connect first. When the shape in (**figure A4.2**) is analyzed, due to a number of symmetries, 8 hot spots with the same ocd of 21 appear. According to principle P1, the first moves would be to connect two hot spots with a five-unit-long line. Hillier's principle of centrality offers the answer to the problem. As it is shown from the tentative trials in (**figures A4.2c** to **A4.2f**), the best solution is C-E with a Loss of 1884. The connection C-E has the most central position as it can be seen from the o-units analysis in (**figure A4.2a**). The centrality of connections is tested by aggregating gd values of corresponding units that the connection covers in the o-units analysis. For instance, while connection A-B covers a sum of 1546 = 304+310+318+310+3104, connection C-E covers a sum of 1082 = 216+216+218+216+216. Hillier's principle of centrality for fitting circulation systems can be restated as follows:

> P2 When more than two alternative hot spots with the same depth value exist in the shape, the most central connection between them gives the most integrated solution. The most central connection is guaranteed from covering units, which have the smallest depth aggregate in the analysis with o-units.

Although global in their significance, hot spots represent local clues in terms of showing where to pass the circulation system in order to achieve the best integration. In contrast, the measure of cf offers a robust description of shapes, and is strongly tied with the potential of introducing a circulation system. Shapes with high concavity, as shown by higher cf values, offer more depth differentiation between regions therefore the choice of inserting the circulation system is clearly channeled through its hot spots. Concave shapes would determine to a large extent the nature of the circulation system to be inserted. In contrast, convex shapes, would present no differentiation for fitting a circulation system, thus they would offer no obvious preference for a particular circulation. For convex shapes without hot spots, the introduction of a circulation is independent from the shape itself; its fitting resembles an inserting that is guided only by geometrical composition principles of the layout rather than shape. In contrast to fragmented shapes, for convex ones, the hierarchical influence of circulation on the combined complex of occupation spaces and circulation spaces would be more significant.

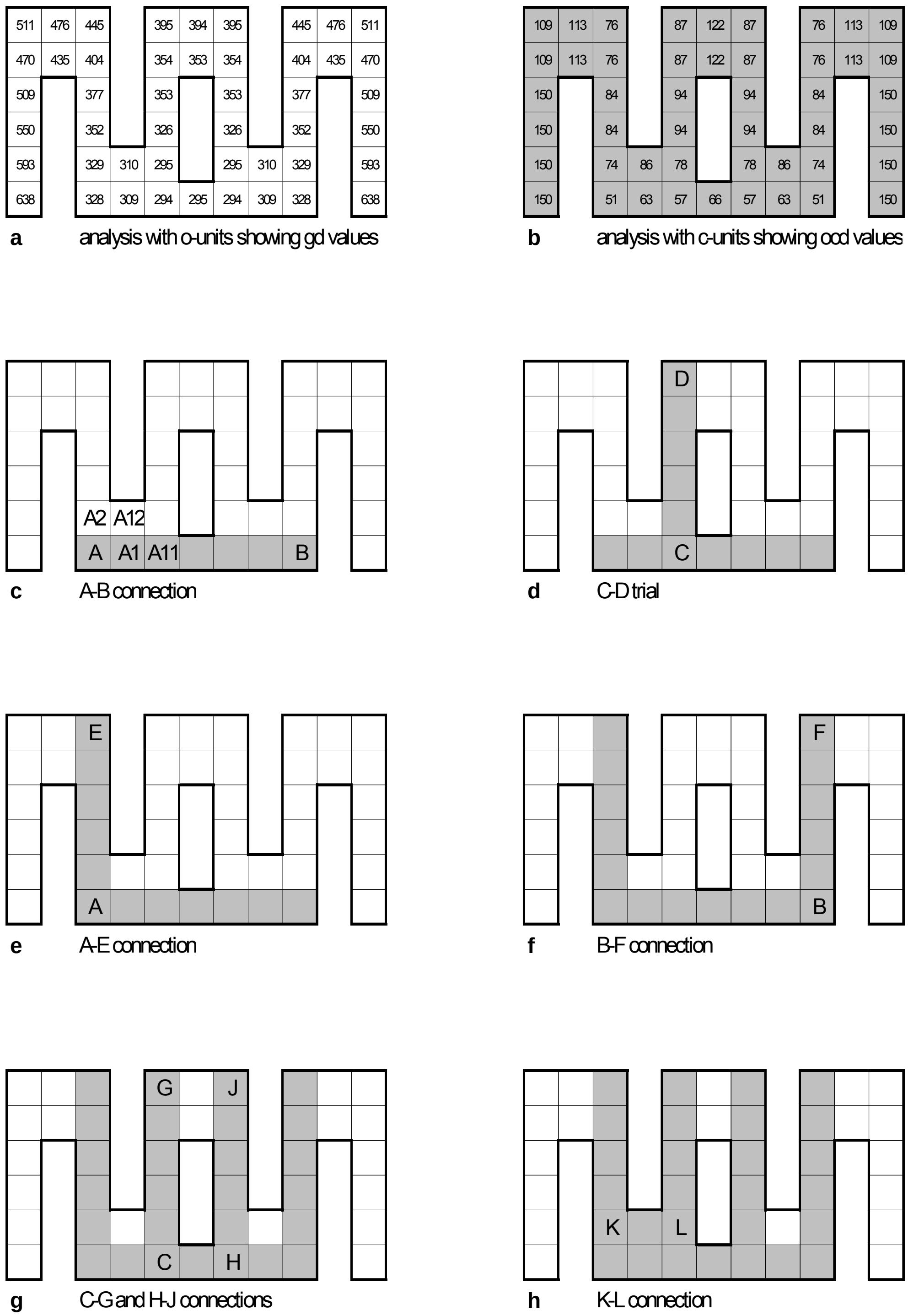


Figure A4.1: Generating a circulation system in a shape by connecting the hot spots.

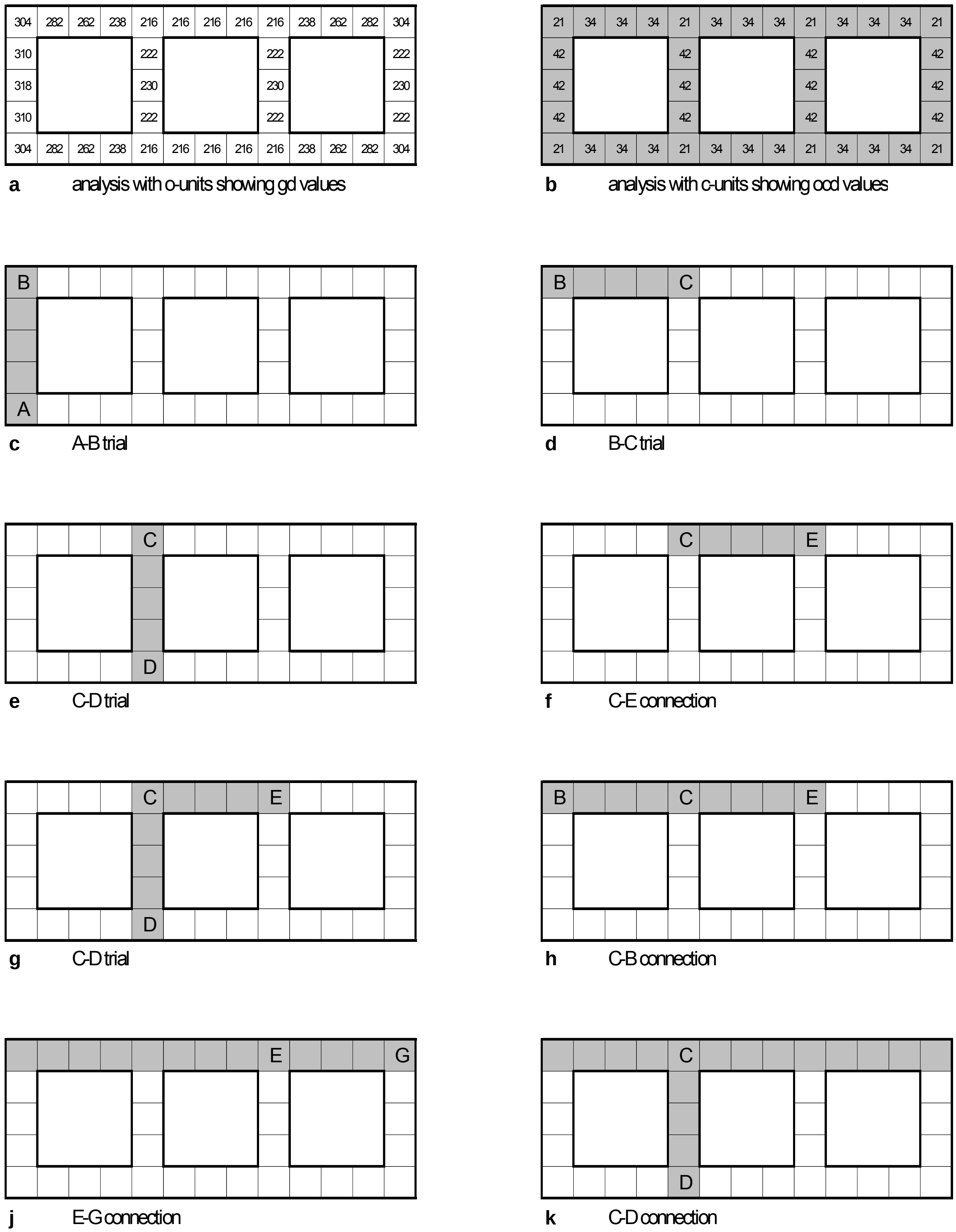


Figure A4.2: Generating a circulation system in a shape which has several hot spots with the same depth value.

Appendix 5 Principles of Generating Shapes by Enhancing Circulation Systems

Often, design protocols constitute of working on a pre-chosen circulation system scheme and fitting a floorplate around it. Choosing in advance a preferred circulation system would to some extent guarantee that the resulting design of the floorplate matches the given criteria. This section investigates whether growing circulation systems into floorplates obeys any principles of the nature of the interaction between shape and circulation.

In the original circulation system o-units are added step by step and the properties of the emerging complex are investigated. Similar to the previous section, the circulation system is analyzed with both o-units (**figure A5.1a**), and c-units (**figure A5.1b**). Given the hierarchy of the circulation system, the first attempts have aimed at improving the circulation system on its own. In (**figure A5.1c**), the circulation segment E-H is 3 depth steps away from D-F, while the metric distance is only 2. Adding an o-cell so that it links the two parts of the circulation system together improves the integration of the complex as a whole better than any other move. We can formulate the first principle of attaching o-units as follows:

> P1 When two parts of a circulation system are metrically closer to each other than depth-wise, connecting them with o-units along the shortest connection gives the best solution for the number of added o-units.

Tentative trials for placing another o-cell adjacent to the circulation system show that the best solution is achieved when the o-cell is placed adjacent to c-units with the lowest depth, i.e. hot spots (**figure A5.1d**). As a result, the first step in attaching o-units to the circulation system is guided fully by the position of hot spots in the circulation. The second principle of attaching o-units is formalized as follows:

P2 Attaching o-units to c-units with the lowest depth values give the most integrated solution for the number of added units.

As all adjacent positions to hot spots are occupied by o-units using principle P2, the next step involves finding where to attach the other o-units. Taking into account the ocd values of units included in circulation segments, for example A-D=20+34+34+34+20=142, the hierarchy of circulation segments from the most integrated to the less integrated is: A-D < D-E = E-G < A-B = C-D = F-G < C-F, reinforcing that segments located between hot spots with lowest depth are the most integrated. The comparison between two tentative moves of adding o-units shows that enhancing first the best integrated segment produces the lowest depth in the complex. The third principle is defined as:

P3 Adding o-units next to circulation segments which span between hot spots with lowest depth value produces the most integrated solution for number of added units.

While it is clear on which segment to attach first, there are choices to be made between different positions along a segment that have the same depth values. For instance, there are six choices to place o-units on the segment A-D where all ocd values equal 34. Placing an o-cell adjacent to another existing o-cell (**figure A5.1f**) leads to a better solution, OCD+GD=3228, than the tentative move of placing the o-unit half way on the segment A-D, OCD+GD=3230 (**figure A5.1e**). The fourth principle of enhancing circulation systems is:

P4 When the depth values of c-units do not offer any differentiation between each other, growing the shape is carried out by means of placing o-units adjacent to as many as possible previously added o-units in the complex.

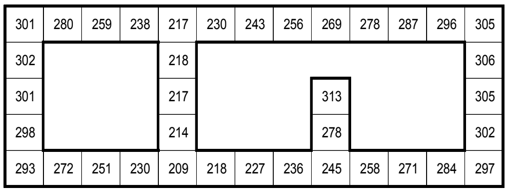
Once the entire circulation has been surrounded by adding the first row of o-units, where principles P1, P2, P3 and P4 have taken effect completely (**figure A5.1h**), the experiment seeks to find clues for adding the best integrating o-units on the second row. First, parts of the circulation closest to o-units to be added are investigated. This is so because nearly all the depth relations of the newly added o-unit will pass through and will be influenced by the c-cell closest to it. Hence, we can think of previously defined principles of attaching o-units in a combined way such that the best solution would be to add o-units as close as possible to low depth hot spots, to low depth circulation segments, and contiguous to as many as possible already existing o-units.

Several trials are carried out adding one o-unit to the complex where the first row of added o-units is completed (**figure A5.2a**). The trial in (**figure A5.2b**) results in a depth GD+OCD=20326; the trial by placing the o-unit closet to a hot spot (**figure A5.2c**), lowers the depth at 20258, whereas the move closer to the other hot spot (**figure A5.2d**) is even better with depth of 20256. However, the trial in (**figure A5.2e**) is kept as an addition since the depth drops into 20250 due to the new o-unit touching two existing o-units in the corner.

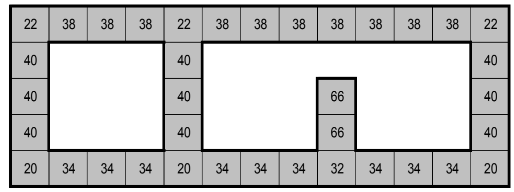
The inner positions represent a more complicated situation since o-units are to be added close to four circulation segments. While both cases show a better integration than the previous moves of rounding the corners, the addition in (**figure A5.2g**) has a lower depth of 20150 than the trial in (**figure A5.2f**) where the depth totals at 20156. The fifth principle of growing shape is:

> P5 In the case of adding o-units next to other o-units and not adjacent to c-units, the best moves are the positions closest to as many circulation segments, then closest to as many existing o-units, and lastly closest to hot spots rather than segments spanning between hot spots.

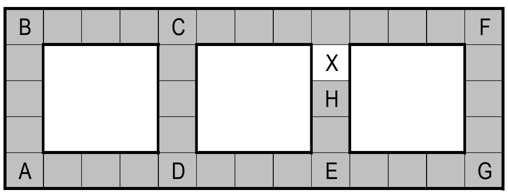
From the cases in (**figures A5.2d** and **A5.2e**) we can see that the adding on corner positions have priority to the ones in the middle of the side of the shape. As a result, the shape will continue to grow maintaining the priority of corner positions and aiming at a rhombus-like form, preserving exactly the facets that are offsets of circulation segments. After several additions, the shape will resemble an octagon where four of the faces have the length of four sides of the circulation system (**figure A5.3**). The structure of the circulation system will be reflected as far as the edges of the shape where stripes with low depth develop along all the extensions of the linear parts of circulation, shown with “x” in the figure. This demonstrates another aspect of the hierarchy of the circulation system on structuring the configuration of the entire shape.



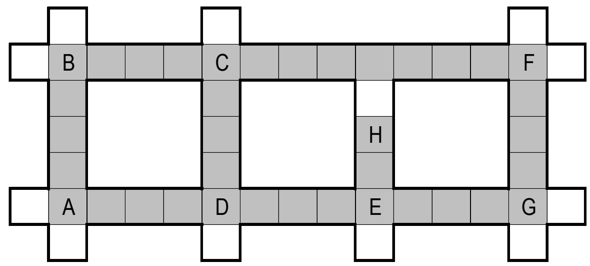
a analysis with o-units showing gd values



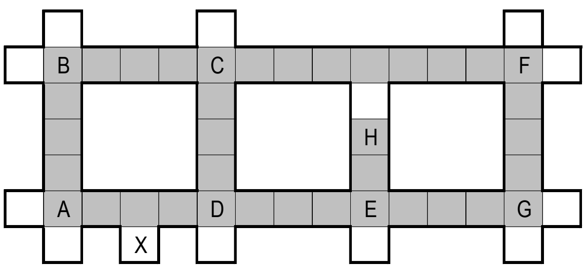
b analysis with c-units showing ocd values



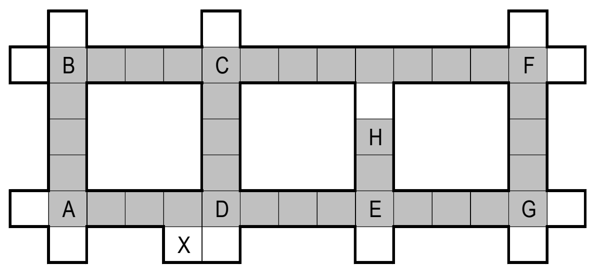
c adding one o-cell to bridge the circulation



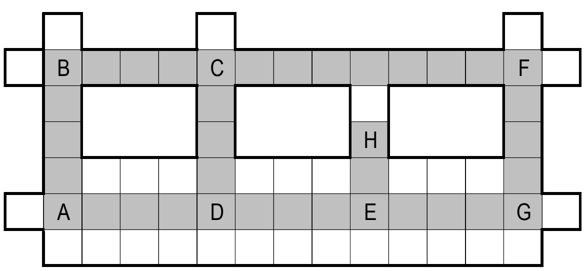
d adding o-cells close to all key spots



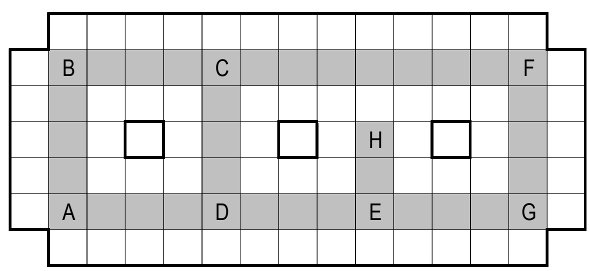
e trial



f addition



g completion of enhancing one circulation segment



h completion of adding one row of o-cells

Figure A5.1: Step by step generation of a floorplate by adding occupation space (o-units) around an existing circulation system (c-units) with the criterion of achieving the lowest overall depth of the complex.

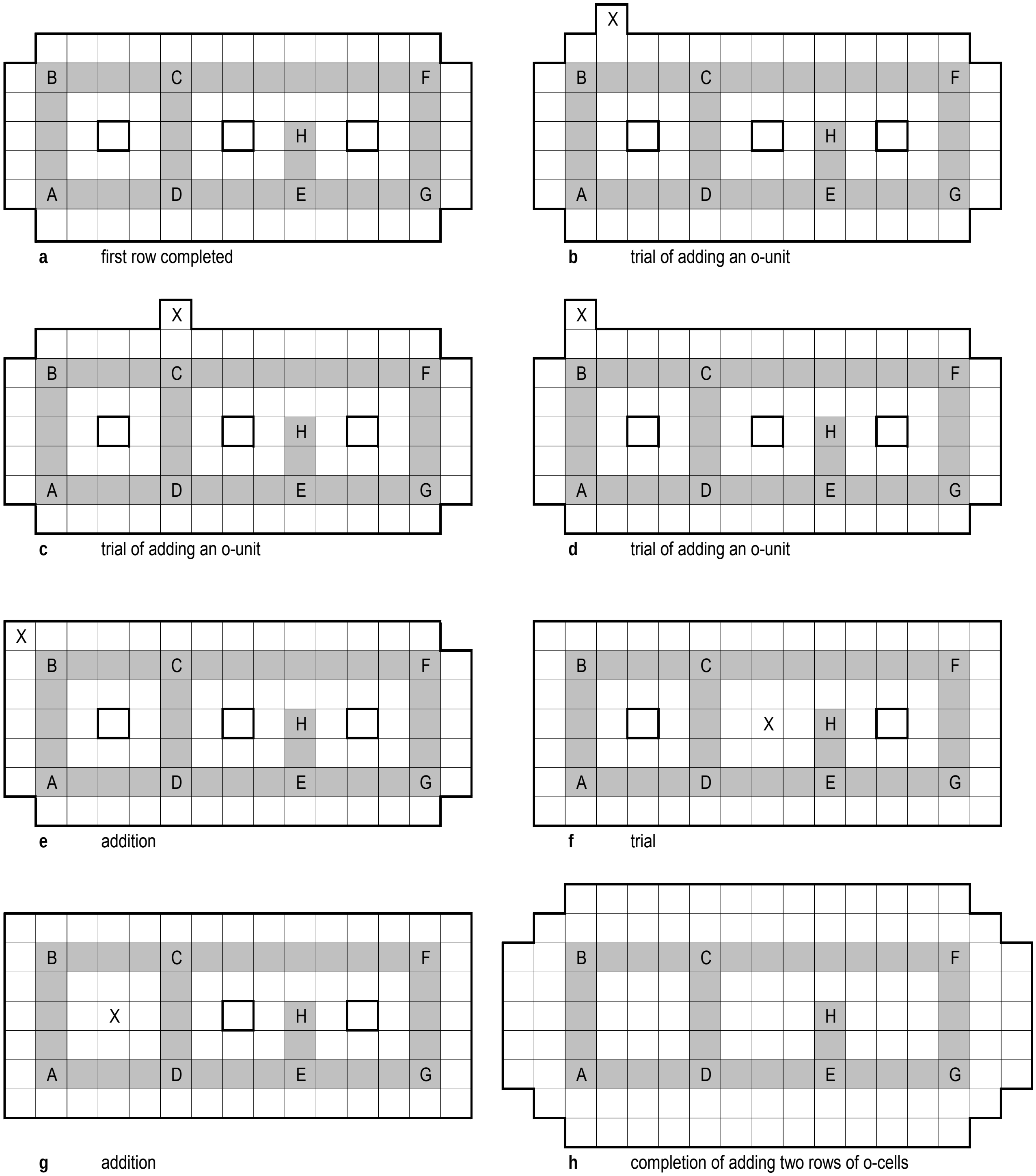


Figure A5.2: Enhancing the shape with a second row of o-units.

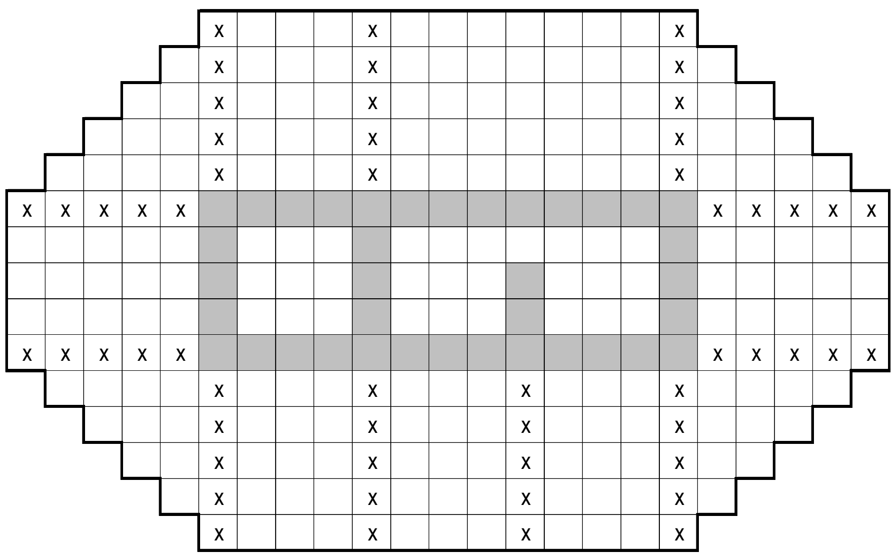


Figure A5.3: The floorplate generated according to five principles of depth minimization. O-units denoted with “x” have lower gd values in relation to the neighboring o-units, thus reflecting the effect of the aligned circulation segments well deep into the shape.

Appendix 6 Computer Application Qelizë

The methodology developed as part of this thesis has included the design and implementation of the computer application Qelizë (Qelizë means cell in Albanian) which enables the calculation of the measures of gd and ocd (Shpuza 2001). The application allows the user to draw by clicking or dragging with mouse three kinds of units, occupation units (o-units) shown in transparent boxes with a red dot in the middle, circulation (c-units) shown in red, and core units shown in gray (**figure A6.1**). The drawing is carried out by sequentially changing the state of the box from nothing to o-unit to c-unit to nothing, whereas core units are drawn by right clicking. The zooming in and out allows for drawing relatively large floorplates in fine tessellation. The “local” mode enables to see the depth spread from any unit the user chooses by mouse. The “global” and “add data” modes calculate and display all the measures, while the “add data” mode adds a line of data in the transfer text area for the purpose of copying and pasting into spreadsheets for further statistical analysis. Another feature of the applet is the text field at the left side of the buttons where a short string of characters can be input. This string stands as a label given to the complex to be analyzed and is automatically added in front of the data line in order to allow an easier reference. For multiple calculations of the same complex or a series of theoretical models, the system adds a number which is incremented by one after each calculation, and is added to the string of the input label. The “color” mode displays depth values in six colors according to the legend on the lower part of the canvas, whereas the “number” mode switches to displaying of numeric values of gd(i) and ocd(i) over each shape unit. The Java applet is accessible from the web, currently at http://www.prism.gatech.edu/~gt7531b/Qelize/qelize.htm.

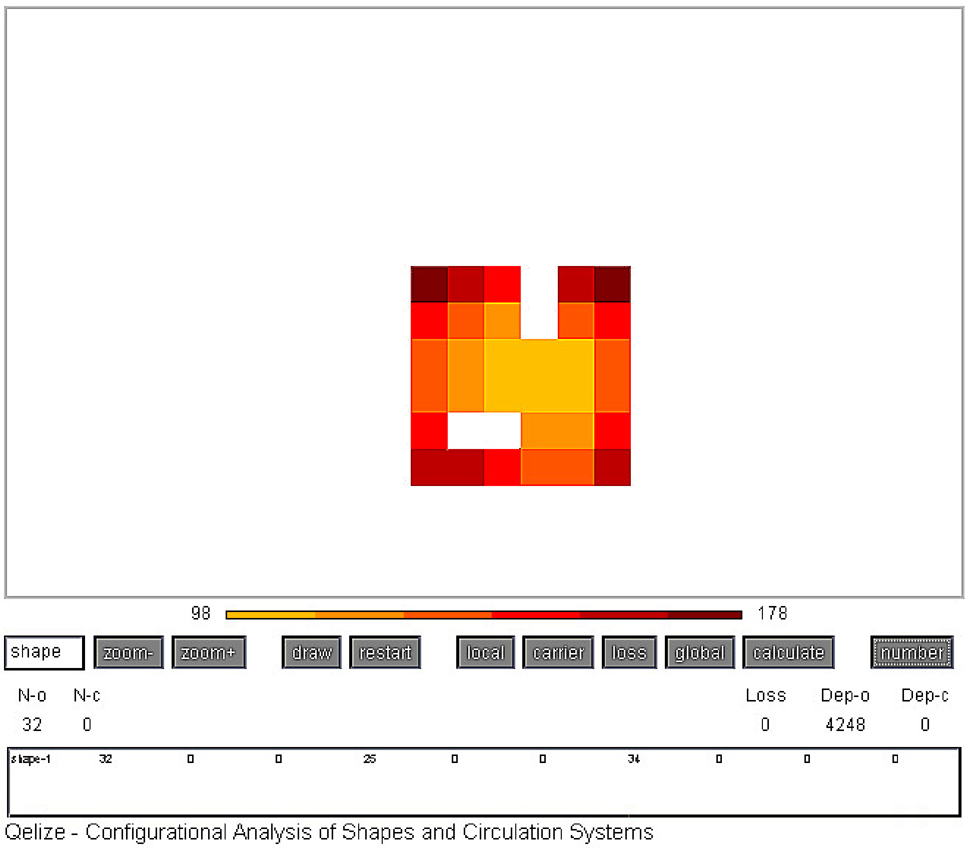


Figure A6.1: The interface of the Java application “Qelizë”

Appendix 7 The Effect of Grain on Layout Integration and Mean Depth

The following experiments are intended to investigate the effect of layout density on the layout measures of Integration and Mean Depth. The index of *grain* is introduced to gauge the density of a given layout in comparison to a yardstick layout. It is calculated by the formula:

$$grain = \sqrt{\frac{c}{c_y}} \qquad \text{(A7.1)}$$

where c is the number of cubicles in one unit of the layout under consideration,

c_y is the number of cubicles in one unit of the yardstick layout.

The ideal layout, where one floorplate unit accommodates four cubicles is taken as a yardstick layout to which other layouts are compared. Hence, a layout where a floorplate unit accommodates 16 cubicles has a grain equal to 2, whereas a layout where a floorplate unit accommodates 64 cubicles has a grain of 4. In addition to the yardstick hypothetical grid layout composed of 144 cubicles, two more layouts with grain of 2 and 4, i.e. with 576 and 2304 cubicles, are inserted on the four basic shapes (a), (b), (c) and (d) (**figure A7.1**). Similarly, two more fishbone layouts with grain of 2 and 4 are introduced on these basic shapes (**figures A7.2**).

The results of analysis are tabulated in **figure A7.3**, where the upper part shows the results of the analysis of grid layouts with three different grains of 1, 2 and 4, while the lower one shows the results of the analysis of fishbone layouts with three grains of 1, 2 and 4. Line charts in **figure A7.4** show the relationship Mean Depth vs. grain and Integration vs. grain for two layout types. Two main findings result by comparing the effect of grain on two layouts: First, for both grid layouts and fishbone layouts, greater grain inflicts greater Integration and greater Mean Depth, however the curves tends to converge towards horizontality. Second, for equal degrees of densification, fishbone layouts cause a greater increase of Mean Depth and Integration in comparison to grid layouts as shown by steeper curves of the lower row. In other words, fishbone layouts are more sensitive to the densification than grid layouts.

In one hand, the first conclusion confirms the finding of the previous chapter about the greater layout integration associated with greater density as made evident by the comparison between U+B layouts and U+S layouts. In the other hand, the densification of layouts has an identical effect to the enlargement of the floorplate area. Hence, for the same layout grain, larger floorplates tend to produce greater integration. In addition, the dependence of Integration from grain or density raises doubts on the relevance of two empirical findings of space syntax research: first, that the density of occupation affects the correlation between Integration and the observed movement pattern (Hillier, Grajewski and Peponis 1987); second, that both the density of occupation and integration correlate to the degree to which contact networks in an organization are found to be useful contacts (Hillier, O'Sullivan, Penn et al. 1990). The density of occupation affects directly the spatial integration; hence the two cannot be listed as independent factors affecting the movement pattern and the usefulness of contacts in office productivity.

The experimentations with theoretical shapes and hypothetical layouts discussed in Chapter 7 use equal degrees of grain for shapes with constant area. Consequentially, the effect of grain is non existent. The experiments with hypothetical layouts and actual floorplates, discussed in Chapter 8, where floorplates of different sizes are involved, also use equal degrees of grain. However, in these cases, the effect of grain, despite minute, is considered as an integral part of the effect of shapes on layouts.

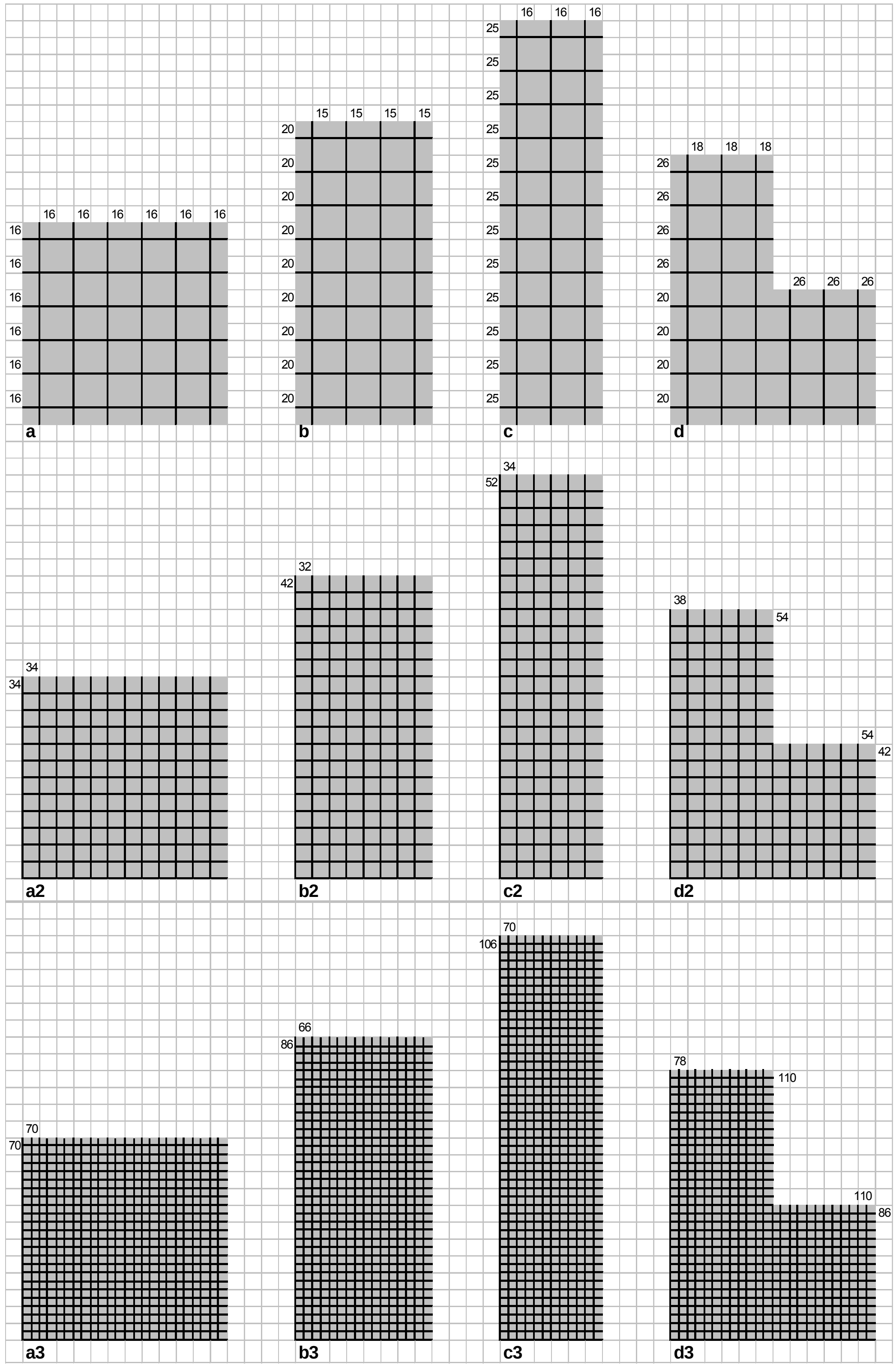


Figure A7.1: Hypothetical grid layouts with grains of 1, 2 and 4 introduced on basic shapes a, b, c and d.

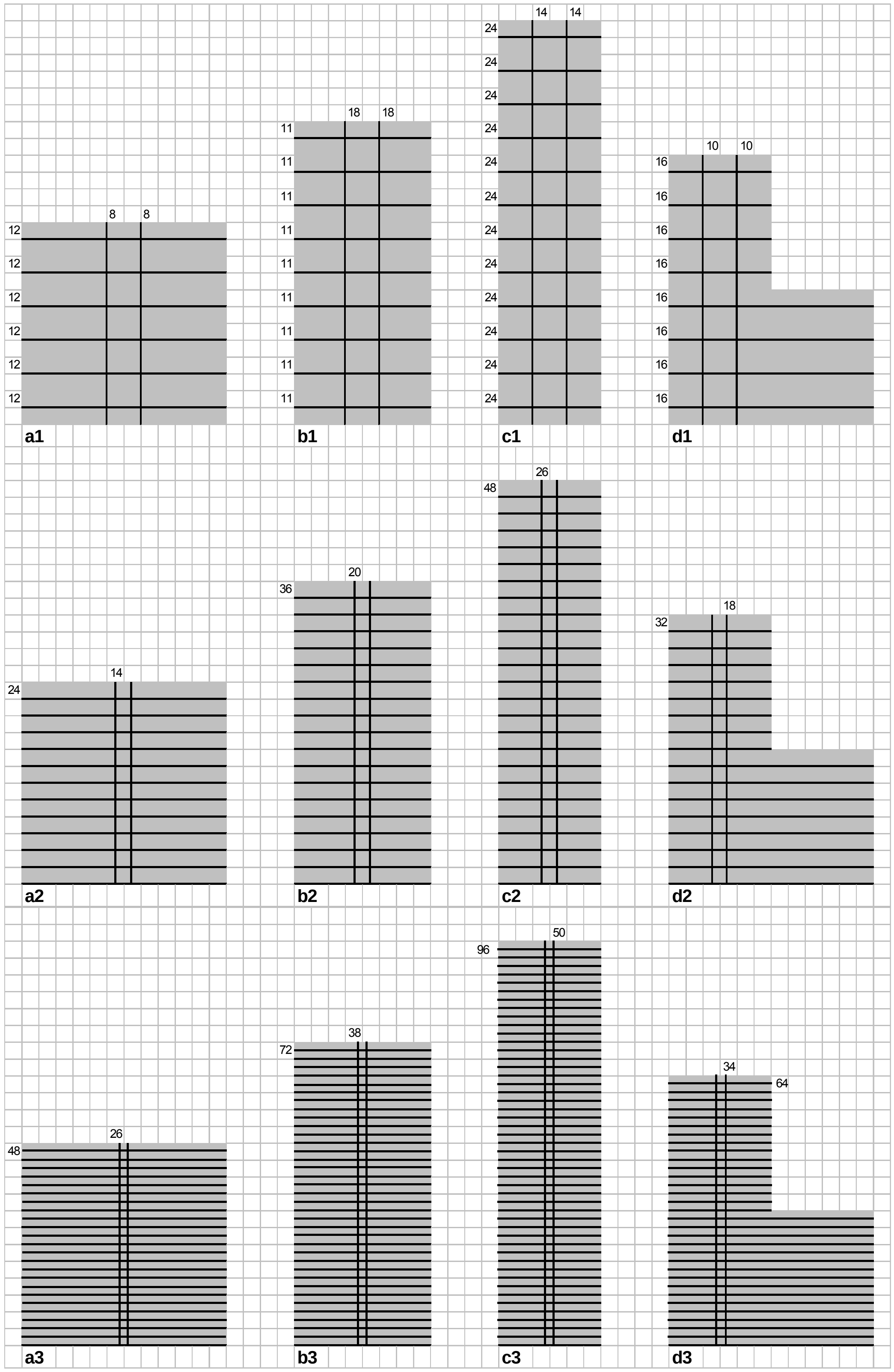


Figure A7.2: Hypothetical fishbone layouts with grains of 1, 2 and 4 introduced on basic shapes a, b, c and d.

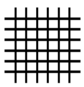
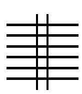
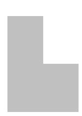
	36 cells		144, 576, 2304 cubicles grain	layout analysis number of lines	 mean MD	 mean integration
	a		1	12	1.454	3.134
			2	24	1.478	4.707
			4	48	1.489	6.427
	b		1	13	1.536	3.439
			2	26	1.557	4.978
			4	52	1.565	6.682
	c		1	15	1.657	4.066
			2	30	1.669	5.493
			4	60	1.675	7.152
	d		1	14	1.736	2.542
			2	28	1.746	3.766
			4	56	1.751	5.091
	a		1	8	1.571	2.758
			2	14	1.736	4.595
			4	26	1.852	6.881
	b h		1	11	1.673	3.770
			2	20	1.811	5.887
			4	38	1.898	8.369
	b v		1	6	1.467	1.939
			2	10	1.645	3.457
			4	18	1.791	5.497
	c h		1	14	1.736	4.595
			2	26	1.852	6.881
			4	50	1.922	9.474
	c v		1	5	1.400	1.478
			2	8	1.571	2.758
			4	14	1.736	4.595
	d v		1	10	1.644	3.457
			2	18	1.791	5.497
			4	34	1.886	7.927
	d h		1	8	1.571	2.758
			2	14	1.736	4.595
			4	26	1.852	6.881

Figure A7.3: Analysis of hypothetical grid and fishbone layouts with grains of 1, 2 and 4 introduced on basic shapes.

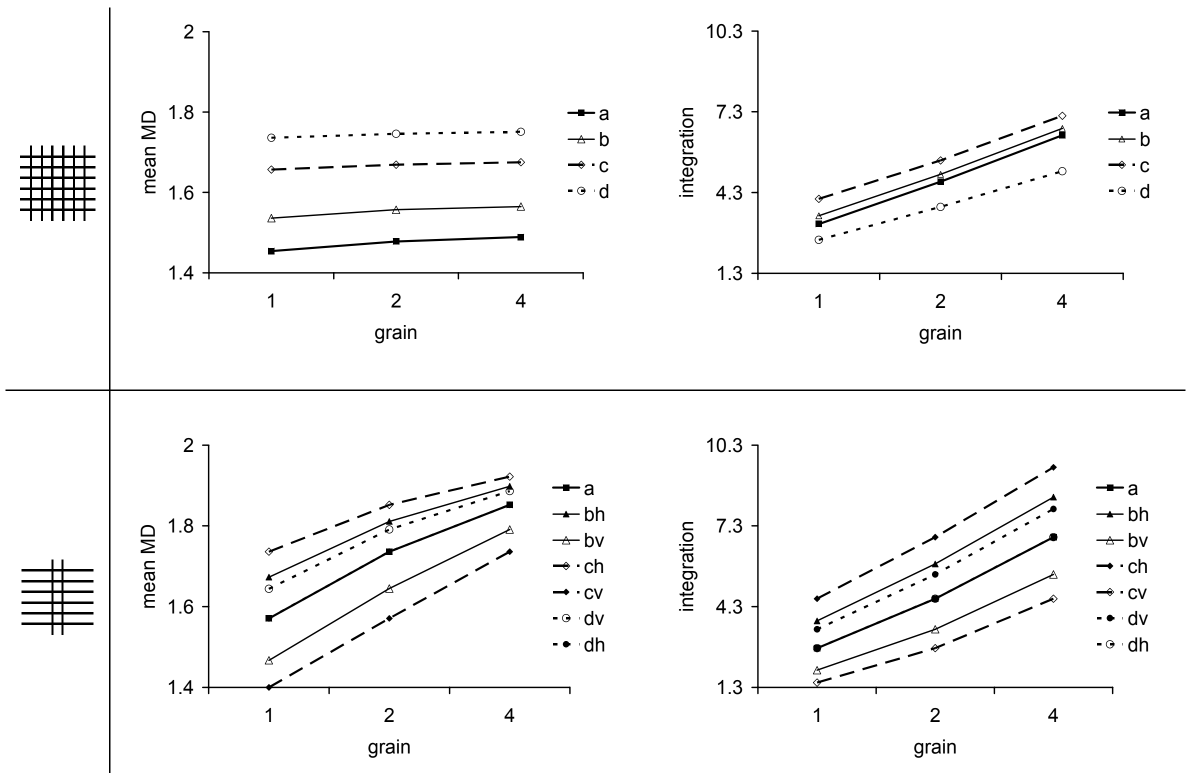


Figure A7.4: Line charts of fits between mean depth and integration versus three degrees of grain for hypothetical grid and fishbone layouts inserted in theoretical shapes.

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Curriculum Vitae

Ermal Shpuza was born in Shkodër, Albania in 1969. He received a professional degree Diploma in Architecture from Polytechnic University of Tirana in 1992. He received a MSc. in Architecture from The Bartlett, University College London in 1995. He is a registered architect in Albania and has practiced as architect in Albania, Malta and the USA. He was an assistant professor of architecture at Polytechnic University of Tirana during the period 1992-1997. Since Fall 2001, he is an instructor of graphics and CAD at Art History Department, Emory University. In Fall 2005, he was appointed to the faculty in the School of Architecture, Southern Polytechnic State University.